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A SIMULATOR STUDY OF DEEPWATER PORT SHIPHANDLING AND NAVIGATION--ETC(U)
JAN 81 R C COOK, K L MARINO, R B COOPER DOT-CG-944467-A
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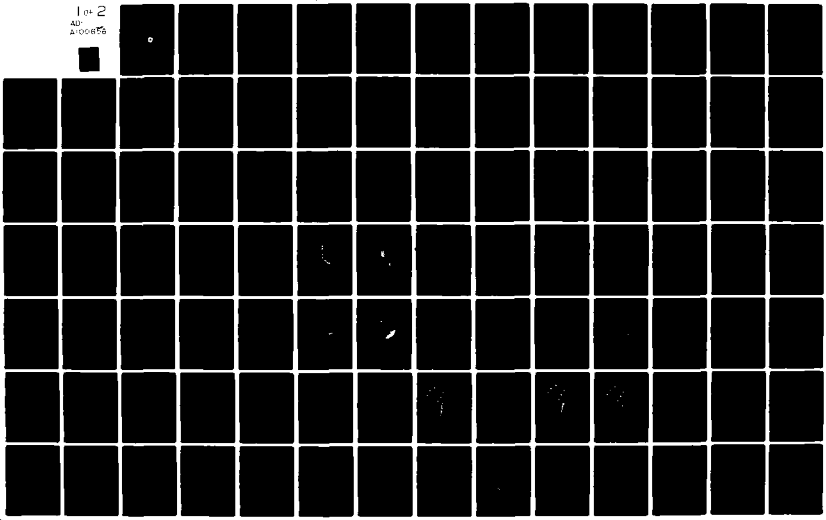

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Report No. CG-D-66-80

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A SIMULATOR STUDY OF DEEPWATER PORT SHIPHANDLING AND NAVIGATION PROBLEMS IN POOR VISIBILITY

LEVEL II

ECLECTECH ASSOCIATES, INC.
NORTH STONINGTON PROFESSIONAL CENTER
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JANUARY 1981

FINAL REPORT

Prepared for

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16. Abstract

The study used a ship's bridge simulator to investigate safety of navigation, the effect of navigation displays, and the effect of bridge personnel organization during low visibility approaches of a VLCC to a deepwater port complex. Experienced VLCC masters and mates, some team trained and team organized, performed over 90 simulated approaches to the Louisiana Offshore Oil Port (LOOP) using either radar, radar with added racons in the area an automatic radar plotting aid (ARPA), or an ARPA displaying fairway boundary lines. Three scenarios were examined: a landfall approach, coastwise approach, approach to pick up the mooring master, and a dead reckoning approach with degraded position information. Strategies which were chosen by the masters in their approaches are described in light of their effect on deepwater port safety. Conclusions derived from descriptive and statistical evidence of performance led to recommendations for relocating the mooring master pickup point, providing an anchorage for use by masters, and the placement and implementation of racons within the deepwater port area. Other recommendations advocate the use of special bridge procedures and navigation systems during port approaches, and further research into the effect of traffic separation or advisory schemes on deepwater port safety. Findings suggest that while approaches of VLCCs to an offshore deepwater port under conditions similar to those simulated are not deceptively difficult or inherently unsafe, there are opportunities to mitigate the potential for hazardous navigation and shiphandling problems.

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navigation risk, navigation safety, navigation workload, shiphandling, ship control, hazard avoidance, trackkeeping, human factors, low visibility, anchorage, pilotage, mooring master, ship simulation, chart design, very large crude carrier (VLCC), supertanker, navigation systems, navigation equipment, navigation displays, bridge displays, aids to navigation, radar navigation, racon, radar, collision avoidance system (CAS), automatic radar plotting aid (ARPA), loran, radio direction finder (RDF), Fathometer, bridge team training, crew organization, bridge procedures, operating guidelines, safety fairway, traffic advisory, traffic separation, traffic lanes

ACKNOWLEDGEMENTS

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Special recognition is due CAPT James T. Montonye, LCDR Leo Vaske, and Mr. David A. Walden, all of the U. S. Coast Guard, for their enthusiastic interest in the project and continued advice throughout its conduct.

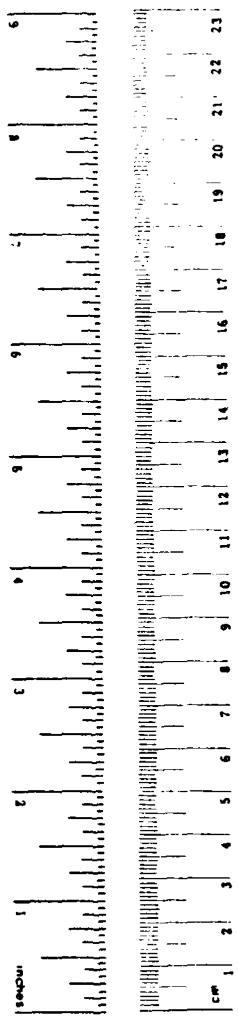
Finally, the authors wish to thank the more than 30 masters and mates from around the world who took time from their busy schedules to provide consultation or act as subjects during the simulation.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

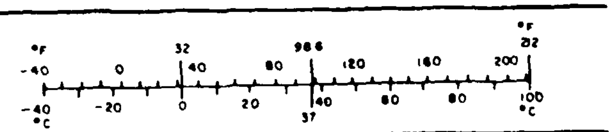
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Section 1

EXECUTIVE SUMMARY

1.1 OVERVIEW

In early 1981, the Louisiana Offshore Oil Port (LOOP) will begin operation as the United States' first offshore deepwater port. Other deepwater port projects are in various stages of planning. These include energy islands off the east coast and inshore deepwater terminal facilities such as those proposed in Galveston and Corpus Christi, Texas. The U.S. Coast Guard, in response to requirements of the Deepwater Port Act of 1974, has undertaken a broad based research program to examine the issues affecting safe operation of large ships in connection with deepwater port operations; and to take action to mitigate hazards which are identified.

Included in the research program have been fast-time simulation studies of vessel maneuvering characteristics to define the size and shape of precautionary areas; hazard and risk analysis to identify and assess the risk of incidents resulting from deepwater port operations; and studies designed to improve hydrodynamic simulation models through empirical measurement and at-sea observation.

This research is a direct follow-on to the study of likely hazards and risks of tanker approaches to an offshore deepwater port. That study concluded that the major navigation hazards were human factors and weather. The areas of highest navigational risk were identified to be the straits entering the Gulf of Mexico and the areas immediately adjacent to the deepwater port where intersecting fairways and the high density of offshore structures complicated ship operations. Low visibility and vessel traffic are other principal hazards expected in the Gulf of Mexico.

A systematic study of low visibility approaches to a deepwater port was needed to reveal hazards in port approaches and to identify any procedural or navigational enhancements that would increase safety.

This is the first U. S. sponsored study to methodically examine the transition of large ships from open ocean operations to the port approach. Previously this pnase of the transit, which may be its most critical portion, has received little attention. The ship's crew, after directing the vessel for several thousand miles across the open ocean, must make a landfall and conduct an approach through an area that may be both unfamiliar and hazardous. Although this study was developed in the context of approaches to the LOOP complex, its findings and conclusions could be generalized to inshore and offshore deepwater ports in the Gulf of Mexico and elsewhere.

The research was conducted using the ship bridge simulator at Eclectech Associates, Inc. to evaluate the safety of deepwater port approaches and identify the effectiveness of display enhancements and bridge team organization on the transits under poor visibility conditions. Twelve very large crude carrier (VLCC) masters and mates representing five nationalities conducted over 90 simulated approaches using radar, radar with racons, and two different automatic radar plotting aid (ARPA) displays. Test subjects were chosen to represent likely users of an offshore deepwater port in the Gulf of Mexico. All transits were conducted in real time using typical bridge and navigation equipment, and charts. Loran, radio direction finder (RDF), and Fathometer information was available.

Care was taken to develop a realistic simulation program to achieve the research objectives. Interviews were conducted with VLCC operators to characterize likely approach processes and strategies. Navigational charts were augmented with the deepwater port fairways and structures. The hydrodynamic response of a 280,000 dwt oil tanker was carefully modeled for all likely maneuvers including slowing, backing, and turning. Displays were developed to represent the characteristics of radar, racons, and ARPAs. Realistic traffic and offshore structure densities were modeled for each scenario.

Both the simulator system and trained observers recorded data throughout the experiment. At the end of each simulation, subject comments [illegible] impressions were also obtained. Results and conclusions of the study are highlighted in the following paragraphs.

1.2 SUMMARY OF FINDINGS AND CONCLUSIONS

Conclusions of the study are based upon a logical chain of evidence from interviews, research notes, simulation observations and a statistical analysis of quantitative data which were recorded during the experiment.

1.2.1 Safety of Navigation in Deepwater Port Approaches

The simulation scenarios provided a maximum freedom of choice to masters in their selection of approach strategies. While hazardous navigational and traffic situations could have developed, no difficulties leading to a collision or grounding occurred. In approaching the mooring master pickup point, proficiencies for speed control and maneuvering were demonstrated to adequately receive the mooring master or from which a safe contingency was possible in the event the mooring master was delayed. When degraded navigation information resulted in an erroneous ship's position, all masters responded characteristically and safely (1) to detect the error, (2) to establish and confirm their actual position, and (3) to maneuver to an appropriate new course for the fairway.

Finally, although all transits were not error free, the waterway design was routinely tolerant of those which did occur. Findings suggest that while approaches of VLCCs to an offshore deepwater port under conditions similar to those simulated are not deceptively difficult or inherently unsafe, there are opportunities to mitigate the potential for hazardous navigation and shiphandling problems.

1.2.2 Effect of Aids to Navigation, Personnel Organization and Bridge Equipment on Deepwater Port Approaches

Conclusions and specific recommendations of the study apply directly to Gulf of Mexico deepwater ports. Many of the findings reported are also relevant to inshore ports and offshore ports in other areas. For example, the study showed that the majority of masters entered and remained within the safety fairway when it was close to the ship's route. For approaches where complying with the safety fairway would have required traveling considerably "out of the way," most of the masters selected a more direct course to LOOP outside the fairways. Masters' selection of points of entry into the safety fairways resulted from tradeoffs in satisfactorily clearing all traffic and rigs, and entering the safety fairway without major maneuvering. Such behavior could be expected at any inshore or offshore port that has safety fairways.

The study also concluded that slowing to pick up the mooring master as well as maneuvering in the event the mooring master is delayed could be significantly improved by (1) removing the dogleg near the pickup point or relocating the pickup point further south, and (2) providing a convenient, well-marked anchorage for use by masters in the event the mooring master is unavailable. Additional recommenda tions to aid in the deepwater port approach are the development of operating guidelines which describe the unique navigational characteristics of the port including rig patterns and racon usage, and a port specific chart of appropriate scale and coordinates.

Conclusions of the study also show that when racons are provided, masters use them as a single point range or for radar parallel indexing. The result is a focusing of tracks toward the racon. Use of ARPA with a navigation option display produced different effects. The clear delineation of fairway boundaries and implied high precision of the system enabled masters to choose alternative tracks either in the center or along the right edge of the fairway.

While both of these behaviors were shown to result in safe operation during the simulation, this study alone cannot determine which of the behaviors is more desirable in terms of deepwater port safety and operating effectiveness. Additional controlled experimentation unique to racon and ARPA utilization is recommended.

The study also concluded that traffic encounters as they were simulated presented no undue hazard or difficulty during the port approach. There were indications based upon demonstrated navigation capability and achieved CPAs that if additional fairway traffic had been present it would have been handled safely. Traffic separation schemes and a traffic advisory service for deepwater ports were not examined in this project. Decisions on these topics should be derived from a more explicit and comprehensive study of the traffic problem.

Comparisons in navigation and shiphandling performance between traditionally organized bridge personnel and team organized crews showed no difference with respect to safety or overall operational effectiveness. These were a number of techniques employed by the team organization which augmented the approaches and demonstrated an increased capability to deal with contingencies. These techniques include preplanning the approach, delegation of duties, review of contingency actions, cross-checking procedures and assuring effective communications. The study recommends implementing certain of these techniques in the deepwater port approach, possibly through operating manuals or port guidelines.

The availability of multiple aids to navigation systems were shown to facilitate the transition from open-sea to the port approach phase of the voyage. Also, during the approach which occurred under conditions of degraded navigational accuracy, multiple aids provided an additional margin of safety and aided in determining actual position. This extra aid further promoted an early initial identification of rig patterns on the radar, thus enabling masters to confirm their position and more judiciously maneuver to the fairway.

Additional findings and subsequent detailed recommendations are presented in Section 5 of the report. While this research supports the conclusions of the earlier deepwater port risk and hazards analysis, that approaches to an offshore deepwater port will normally be safe and routine even under moderately severe environmental conditions, the research raises additional major issues relevant to port design, operating procedures, navigation systems and personnel qualifications.

Section 2

BACKGROUND AND OBJECTIVES

2.1 PURPOSE OF THE RESEARCH

Although about 100 offshore oil ports exist around the world, the first offshore deepwater port to be constructed in the United States will begin operation in 1981. The Louisiana Offshore Oil Port (LOOP) is located in the Gulf of Mexico approximately 40 miles west of the Southwest Pass into the Mississippi River. The U.S. Coast Guard has a variety of responsibilities under the Port and Tanker Safety Act of 1978 and the Deepwater Ports Act of 1974 related to LOOP and subsequent offshore ports proposals. These responsibilities have prompted a broad research program aimed at evaluating and minimizing potential hazards to navigation and risk of oil spills resulting from tanker operations associated with operation of a deepwater port.

Under most conditions, the approach of very large crude carriers (VLCCs) to a deepwater port should be routine, uncomplicated, and safe. The approach has been aided by the designation of safety fairways and vessel traffic advisory services provided at the deepwater port facility. Nevertheless, VLCC masters approaching the port can encounter a combination of hazards. Immediately adjacent to the fairways are oil and gas production platforms. There is consistent small boat traffic between rigs and around fishing grounds and other VLCCs transiting into and out of the facility. The use of safety fairways is not mandatory, and those fairways may not always provide the most economical routes to a vessel's destination. Poor visibility is not unusual in the vicinity of deepwater ports. Unusual current conditions may also be encountered. Any one or all of these factors could lead to "competent" errors on the part of a shiphandler in the vicinity of a deepwater port which would induce significantly increased risk of an oil spill accident.

Navigation and shiphandling during poor visibility in and about the deepwater port proposed for construction in the Gulf of Mexico are made difficult by a combination of conditions. The principal factors contributing to these difficulties are the lack of easily identifiable landmarks on radar and the potential for misinterpreting radar patterns from surrounding oil rigs, vessels, and aids of navigation. A recently completed study[1] indicates that oil spillage risks associated with navigation of large tankers into and through the Gulf of Mexico to the Louisiana Offshore Oil Port (LOOP) deepwater port are not large and appear smaller than for alternate modes of shipment. Nevertheless, the U.S. Coast Guard is endeavoring to reduce these few risks even further.

This project is only one element in the broad Coast Guard research program to address issues related to the safety of operation of VLCCs in association with offshore deepwater ports.

Previous research into deepwater port vessel operations attempted to evaluate potential hazards to navigation and oil spill risks resulting from tanker operations associated with a deepwater port in the Gulf of Mexico and examined the necessary

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[1] Faragher, W.E., J.T. Pizzo, et al. Deepwater Ports Approach/Exit Hazard and Risk Assessment. Report Number CG-D-79, February 1979.

size and configuration of safety and precautionary areas surrounding a deepwater port.[2]

Results of the studies were not totally conclusive based in part on inconsistency of relevant data and because there was no direct deepwater port data upon which to base the risk evaluations. Nevertheless, the Coast Guard was able to conclude that the means of mitigating the hazards associated with deepwater port operations may be more procedural and commonplace and do not require exotic, high technology solutions. The simulation study reported herein was conducted to complement the findings of the hazard and risk assessment by providing a characterization and understanding of the likely transit strategies and performance data associated with approaches to an offshore deepwater port in poor visibility. It provided the opportunity to examine large vessel transits associated with port approaches under controlled conditions. Through this process investigators identified the important elements of the approach process and the impact on VLCC operator approach strategy as a function of navigation display enhancements and bridge personnel organization.

The results of this study provide important insights into the port approach process and suggest possbile operating procedures and general navigation enhancement options which would impact the safety of vessel transits through the area.

While the experiment was conducted using a LOOP area approach scenario, the findings of this report are not uniquely applicable to LOOP. Instead, they can be considered appropriate for general application to port approaches where safety fairways, stationary and moving hazards, and the potential for ambiguous radar patterns exists.

2.2 OBJECTIVES OF THE EXPERIMENT

The objectives of the deepwater port simulation study were to:

- Determine which combinations of hazards, if any, present serious precision navigation problems to VLCC masters in the vicinity of the deepwater ports and which mitigating measures appear most desirable in terms of effectiveness, timing and ease of implementation.
- Appraise the value of potential electronic aid enhancement that may be more generally applicable to offshore and shoreside ports, and the full mix of vessels that use them.

To accommodate these research objectives, an experiment was designed in which experienced VLCC bridge personnel would be permitted through simulation to enter a deepwater port complex much as they would in real world conditions. Controlled variables were introduced in order to examine the full spectrum of proposed deepwater port operations. This included varying the type of bridge personnel organization, the navigation equipment available to them, and the possibility of approaching the complex from different geographical locations or with degraded navigation information as a result of equipment failure.

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[2] Ibid.

Since prior to the study it was relatively unknown how masters and mates would operate in the deepwater port environment, a review of relevant research and interviews with numerous VLCC crews was conducted. This endeavor, known as the presimulation process, laid the groundwork for the selection of experimental variables, the detailed design of scenarios, and for the measures employed in the evaluation of performance.

Section 3

THE EXPERIMENT

3.1 DESCRIPTION OF PRESIMULATION PROCESS

Before designing the experiment and data collection methodology, a review of relevant research and interviews with VLCC masters and mates regarding deepwater port approaches was conducted. The highlights of this presimulation process are presented in the following sections.

3.1.1 Review of Relevant Research

In September 1977, the U.S. Coast Guard initiated a program to evaluate potential hazards to navigation and assess the risk of oil spills resulting from deepwater port tanker transits in the Gulf of Mexico.[3] This study used the U.S. Coast Guard's Vessel Casualty Reporting System (VCRS), Pollution Incident Reporting System (PIRS), Tanker Casualty Files (TCF), and at-sea observations to identify causal factors resulting from a potential vessel accident in and around deepwater ports. As a result, the study made basic assumptions regarding tanker operations and deepwater port transits.

The project compiled a hazard criticality index which reflects the relative contribution of each hazard to vessel operations over the deepwater port transit. The results of this analysis are shown in Table 1. Since the objectives of the deepwater port simulation study are to address all potential navigation and shiphandling hazards in approach to the LOOP complex, categories 2 through 5 of the Composite Hazard Ranking appeared applicable. Otherwise all other applicable hazards identified in the report were considered in the design of the experiment.

In 1976, during a standardized bridge study[4,5] conducted for the Maritime Administration, at-sea performance data was collected aboard a variety of merchant vessels. Data collected during the study included documentation of deck officer performance aboard tankers in the Gulf of Mexico between New Orleans, Louisiana and Port Arthur, Texas. Radar contact and workload data were coded and compiled for computer analysis. Workloads based on the observed performance were then projected to describe future open sea, U.S. coastwise and English Channel operations. Those data pertaining to task allocation, navigation tasks performed and time to complete typical tasks were used to characterize hardware requirements and predict subject activity prior to deepwater port simulation experiments.

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[3] Ibid.

[4] Bertsche, W.R. and A.J. Pesch. An Automated Standardized Bridge Design for the U.S. Merchant Marine. Report Number EAG-76-38006, U.S. Department of Commerce, Maritime Administration, January 1977.

[5] Bertsche, W.R. and J.A. Walsh. "Impact of Bridge Design on the Navigation of Ships." Presented to the International Association of Lighthouse Authorities, 1979.

TABLE 1. COMPOSITE HAZARD RANKING

Category 1 Straights and Channels		Category 2 Open Gulf		Category 3 Safety Fairway		Category 4 Traffic Separation Scheme		Category 5 Safety Zone	
Personnel fault	4	Weather	5	Weather	3	Weather	3	Personnel fault	5
Weather	4	Offshore rigs	3	Offshore rigs	3	Low visibility	3	Weather	5
Vessel traffic	3	Debris	3	Low visibility	3	Personnel fault	2	Low visibility	3
Debris	3			Debris	3	Vessel traffic	2	Moored vessels	3
Depth	2			Personnel fault	2			Currents	2
Low visibility	2			Vessel traffic	2			Vessel traffic	2
Anchored vessels	2			Depth	2			Offshore rigs	2
Currents	2							SPMs	2
Restricted space	2								

Code: 5 = highly hazardous, 4 = very hazardous, 3 = hazardous, 2 = not very hazardous

(After Faragher, Pizzo et al, 1979)

Analysis of the Navigation Function Performed At Sea. The term navigation function collectively describes tasks performed by mates on the bridge which related to position fixing of their vessel. The tasks included acquiring visual and electronic fix data, plotting the fix data on charts, performing related navigation calculations, reviewing navigation publications, and updating charts. Table 2 illustrates the observed navigation workload distribution as a percentage of overall bridge time. Workload during collision avoidance, communications and other watch functions was also reviewed. Percentage of time allocated to these tasks, however, was found to vary widely by circumstances not unique to port operations. As a result, this workload distribution is not reported.

Operator performance during an approach to an offshore deepwater port in the Gulf of Mexico is expected to be similar to a U.S. coastwise transit where reliance on radar navigation will prevail and loran or satellite fixes will be used to augment radar fixes.

It was expected that about 10 to 15 percent of the mate's time would be dedicated to navigation tasks during the simulation runs. The data base also indicated that negligible differences appear to exist between navigational workloads at night and during the day in restricted waters. An increase in navigation workload was observed, however, during periods of poor visibility and in the presence of increased navigation hazards (i.e., in more restrictive waters). These data indicate that although a relatively equal amount of time was allocated to obtaining fixes, the mate spent additional time rechecking and verifying his fix in the presence of increased navigation hazard.

TABLE 2. NAVIGATION WORKLOAD DATA RECORDED AT SEA*

Workload	Percentage of Time			
	Open Sea	U.S. Coastwise	English Channel	English Channel Limited Visibility
General navigation tasks	3.2	4.8	8.0	22.2
Plot all fix data	3.0	3.8	5.4	9.4
Obtain radar data	0.5	1.4	0.9	1.5
Obtain loran data	3.4	0.5	--	--
Obtain Decca data	--	--	1.1	0.8
Obtain RDF data	--	--	--	--
Obtain fathometer data	--	0.1	--	--
Obtain visual bearings data	0.1	2.3	0.4	0.7
Obtain sun and star fix data	--	--	0.1	--
Total all navigation tasks	10.2	12.9	15.9	34.6

*From Reference 4

Electronic Fixing Tasks and Equipment. Analysis of workload data indicated that the average time to obtain and plot fix data does not vary significantly as a function of equipment used. Figure 1 illustrates that the average time required to plot a navigational fix varies from 90 seconds for a radar range and bearing to about 2 minutes for loran coordinates, Decca coordinates or latitude and longitude. It is due to these relatively small differences observed, that loran data obtained during the simulation will be provided as latitude and longitude, representative of output obtained by an commercial loran receiver and processor.

Additional evidence indicated exclusive reliance on loran, omega, satellite, etc. in open sea operations. Fixes were taken about once an hour. Radar appeared to be the primary navigation tool used in U.S. coastwise operations and in the English Channel. In the coastwise transits, frequency of fixes increased to about three per hour.

Two other navigation systems, the Fathometer and RDF were seldom used. The Fathometer was utilized primarily for detecting depth contours when making a landfall. The RDF was also used at this time to obtain bearing information on key aids to navigation.

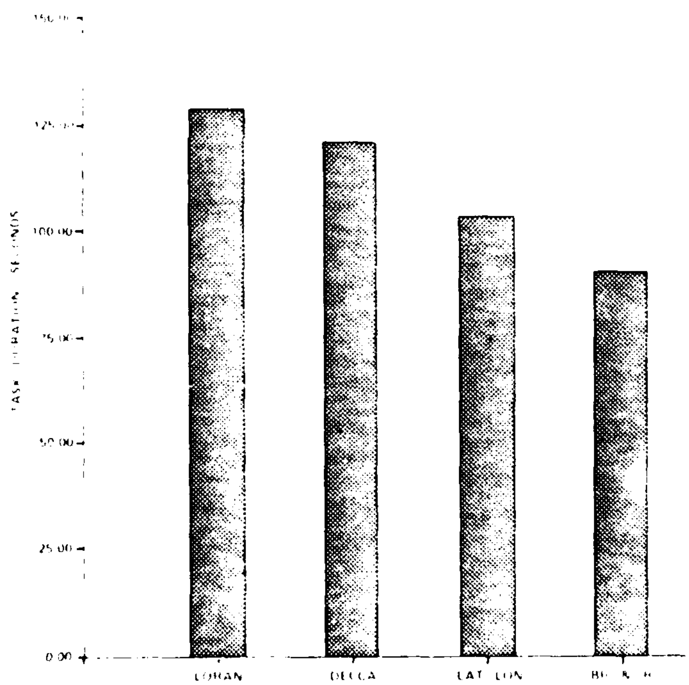

FIGURE 1. AVERAGE TIMES REQUIRED TO PLOT NAVIGATIONAL FIX DATA

3.1.2 Summary of Master and Mate Interviews

Because the LOOP project is not yet operational, there are no pilots or VLCC masters familiar with its operation. To augment the hazard and risk analysis and to improve the characterization of the likely navigation process associated with approaches to LOOP, interviews were conducted with mariners who had combined experience in (1) the Gulf of Mexico, (2) other deepwater port installations, and (3) VLCC operations. These individual subject qualifications are summarized in Table 3.

The interviews were structured to reveal a characterization of VLCC transits to an offshore deepwater port such as the LOOP complex. Charts of the Gulf of Mexico and local LOOP vicinity were provided for annotation and discussion. Each interview subject was asked to project himself into the LOOP operating area from either the Florida Straits or the Yucatan. As the discussion focused on the approach to the LOOP safety fairways more detail was elicited from the masters regarding their use of speed, radar, personnel, and navigation aids to assist their approach to the deepwater port.

Following the description of a routine transit to a Gulf Coast deepwater port, discussions of operating limitations, risks, and additional navigation assistance were conducted. These identified possible navigation display enhancements that would be of significant assistance during vessel transits to the deepwater port. The interviews were open ended to cover all the desired material without unduly

TABLE 3. INTERVIEW SUBJECT EXPERIENCE AND QUALIFICATIONS

SUBJECT 1	38 years licensed deck officer 13 years as a master Currently master of 265,000 dwt VLCC Current operations — Persian Gulf and Phillippines
SUBJECT 2	35 years licensed deck officer 20 years as a master Recently retired master of 265,000 dwt VLCC Significant experience in the Gulf of Mexico
SUBJECT 3	36 years licensed deck officer 23 years as a master and pilot Currently master of a 165,000 dwt oil tanker Current operations – Alaska to Panama Canal Little experience in the Gulf of Mexico
SUBJECT 4	Current masters license – serving as chief mate Currently operating Panama Canal to Gulf Coast Ports Significant experience in gulf coastal operations
SUBJECT 5	39 years as a licensed pilot VLCC pilot and pilot instructor at Limetree Bay, St. Croix Piloted over 200 VLCC's in excess of 100,000 tons Consultant on pilotage matters

influencing the masters. In this way the interviews obtained the desired information devoid of preconclusions. The results presented in the following paragraphs summarize this sample group's prior assessment of the way in which they would transit and improve the navigation system associated with Gulf of Mexico deepwater port operation.

Use of the Safety Fairways. The consensus was that the fairways were placed along a reasonable track from either the Florida Straits or the Yucatan. For the most part the subjects stated that they would routinely use the fairways. The master's previous operational experience in gulf coastal operations appeared to influence his expected use of the fairways. The most experienced masters felt least inclined to insist upon use of the fairway, and the master with the least experience in the Gulf of Mexico indicated that he would enter the safety fairway well to the south of the existing east-west safety fairway. Several of the masters commented that although use of the fairways was not mandatory, they assumed that casualties occurring outside of the safety fairways would impose an additional liability on the vessel master for not keeping to the established shipping lanes. All of the masters commented on the jogs in the safety fairway, prefering that the approach be as straight as possible.

Navigation Systems. During the open ocean approach to a deepwater port, initial reliance would be on celestial and long range electronic aids such as satellite and loran. These aids would be augmented by interpretation of radar displays, Fathometer, and radio direction finding equipments as the vessel began its approach to the fairways. Several of the masters indicated that they would continue to rely on loran and satellite navigation systems well into the safety fairways, using the local aids primarily as back-up to confirm the electronics systems. Where the radar patterns began to provide a clear indication of the ship's location, there would be a shift to radar navigation for the final phase of the approach. Masters indicated that they would use radar fixes on identified rigs to monitor their ship's position. One master said that where possible he would align his track with rigs on radar much the same as a pilot would use a visual range to navigate a channel. Fix frequency would vary, while the masters implied that they would determine their position frequently, it appeared that actual plotting of fixes on the chart would occur from 15 minute intervals to hourly.

Radar Range Scales. The masters stated that they would typically use longer range scale (24 miles) during the initial approach to the safety fairways. As they proceeded up the fairways, their attention would focus on the area 10 to 12 miles from their vessel. Due to the expected high concentration of rigs and vessels in the immediate vicinity of the deepwater port, they would prefer to focus on closer-in conditions. One master stated that he used a rule of thumb for selection of a range scale which allowed him to observe the area within one-half hour steaming from his vessel. All of the masters indicated that they would change range scale periodically to examine significant contact threats or to orient themselves to the larger area. All agreed that land returns in this area were unreliable as navigation aids.

Minimum Clearance to Offshore Oil Rigs. The masters interviewed indicated that they would maintain a minimum clearance from offshore rigs of from 1/2 to 2 nautical miles. They did not appear to be concerned with the existence of the rigs even under poor visibility conditions. Masters' primary concern was the presence of uncharted rigs and the small supply craft which accompany rigs. For the most part the rigs would: (1) provide recognizable patterns on radar, (2) serve as aids to navigation, and (3) tend to add to the radar contact level, and consequently to the overall radar workload.

Environmental Conditions. The masters tended to minimize the effect of wind on a fully loaded VLCC. Current could become a problem if the vessel was required to wait for the mooring master to arrive at the pickup point, but concern over environmental effects on approach operations was limited to the severe "northers" and hurricanes experienced in the Gulf of Mexico.

Bridge Watch. The masters agreed that they would be on the bridge, and controlling the ship during the approach to the deepwater port. Along with a mate and helmsman, they would conduct the transit under normal conditions. In severe weather or limited visibility an additional lookout and/or radar operator would be added to the bridge team.

Risks and Hazards. All of the masters interviewed felt that transits to a gulf deepwater port would be routine and safe under normal conditions. Their universal assessment was that the presence of traffic was the most significant hazard associated with the port approach. Fishing vessels, offshore supply boats, and crossing coastal traffic were specifically identified. Other hazards mentioned by the masters were uncharted rigs, excessive vessel speed, and reported obstructions identified on area charts.

Transit Speeds. Figure 2 illustrates the point at which masters indicated they would be at maneuvering speed. While this point varies over a 20 mile band, it appears to illustrate the master's perception of where the open ocean transit and the port approach begins. Those masters most familiar with operations in the Gulf of Mexico tended to wait longer to reduce from sea speed, and the master who indicated that he might maintain sea speed to within 7 or 8 miles of the precautionary zone was the only non-VLCC master.

At approximately the point where an oil rig is just to the west of the safety fairway, all of the masters would begin to slow toward a final mooring master pickup speed of 2 to 3 knots. One of the masters stressed that speed changes should be made continuously from maneuvering speed to final approach speed and that the vessel's speed versus time curve should be a straight line at any point in the approach. This would provide a smooth transition to the pickup point and alleviate the problem of excessive speed in the final approach and delays caused by slowing too soon.

Failure of the Mooring Master to Meet the Ship. In the event that the mooring master did not arrive at the pickup point on schedule, the masters felt they could maintain their position in the fairway for up to 2 hours. If the anticipated delays exceeded 2 hours, the masters indicated that they would leave the safety fairway and anchor in the vicinity of the precautionary zone. Individual preferences for the anchorage (Figure 2) were based on avoiding other traffic or rigs and finding shallow water to anchor.

Preferred Navigation Enhancements. All of the masters had experience with racons and felt that racons in addition to the one on the pumping platform would assist the transit. The desired location of one additional racon is indicated on Figure 3. Typically, the masters were looking for an aid to navigation placed at the intersection of the east-west and north-south safety fairways. Several of the masters indicated a preference for buoys to mark the final leg of the safety fairway. One of the masters stated that in his mind he organizes a voyage by stages. Stage one is the open ocean transit. The transition from stage one to stage two is marked

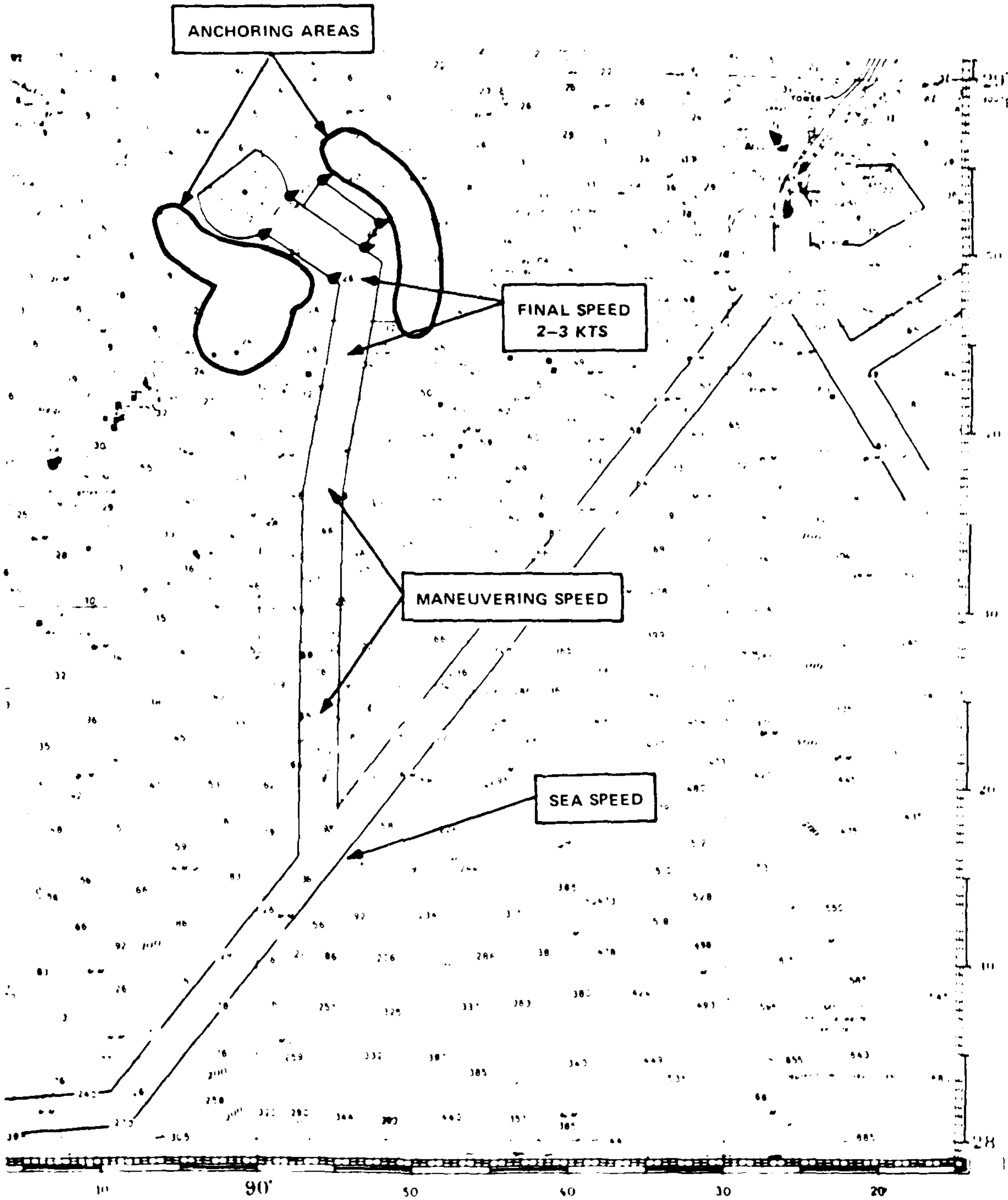

FIGURE 2. MASTER PREFERENCES FOR DEEPWATER PORT APPROACHES

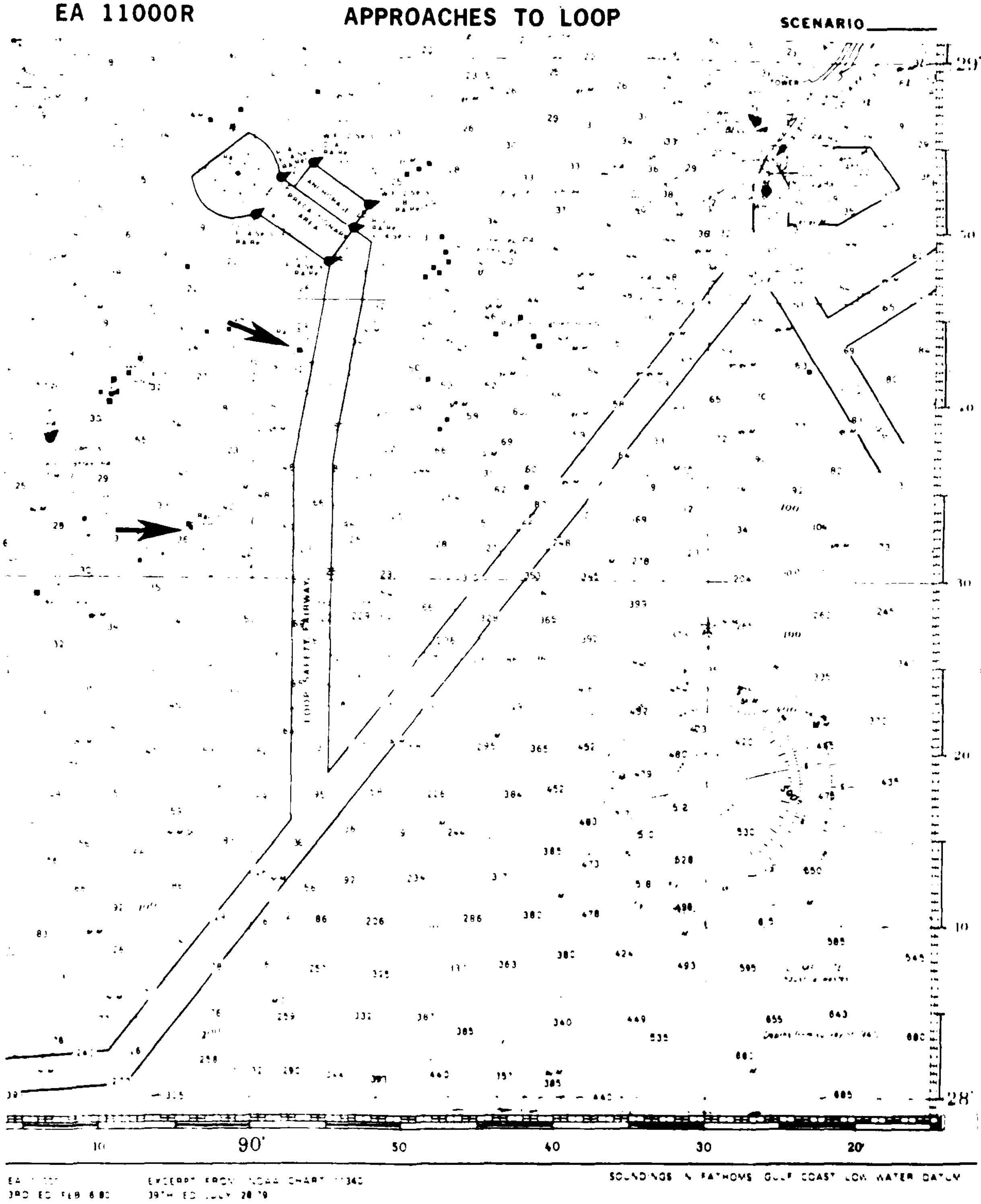

FIGURE 3. POSITION OF ADDED RACONS

by a point of departure, preferably something physical, which tells the master that he has arrived and is beginning the port approach phase of his transit. If there are no physical objects to sight visually or detect on radar in that area, the two stages of the transit may overlap, contributing to confusion of strategy and procedure. Two additional stages in the scenario which he discussed would take the ship through the slowing process to pickup the mooring master, and finally to the single point mooring.

Summary. The interviews conducted during the presimulation phase of the project helped to augment more general performance data and characterize the operation of large tankers during their approach to a Gulf of Mexico deepwater port. For the most part, the masters felt that the approach was not a difficult one, and that the local aids to navigation would be adequate for routine transits. The results of the interviews were then used to develop realistic and believable scenarios for subsequent simulation of deepwater port approaches.

3.1.3 Navigational Equipment Accuracies

Solutions to the navigation problems experienced in deepwater port safety fairways and approaches to a deepwater port complex were addressed through a review of relevant literature[6,7] as well as access to the at-sea data base and discussions with user and provider (i.e., USCG) personnel. Errors customary in the navigation systems found at proposed deepwater port facilities were identified for inclusion in the simulation. Bias or propagation errors unique to the LOOP area were not simulated. Table 4 shows the results of a navigation equipment errors analysis conducted for the U.S. Coast Guard's aids to navigation study[8]. The following equipment errors were incorporated in the simulation based upon the analysis and capabilities of the simulator facility. All are considered appropriate for a VLCC approach to a deepwater port facility such as LOOP.

3.2 EXPERIMENTAL VARIABLES

The variables examined during the simulation experiment were selected as a result of the presimulation process and the requirement to fulfill objectives of the overall project (Section 2). Although the scenarios themselves represented approaches to the LOOP complex, experimental variables were selected which permit extrapolation of conclusions to other deepwater ports.

The two major variables of the experiment were bridge personnel organization, traditional or team trained; and type of navigation display enhancement, whether radar alone, radar with racons, ARPA (automatic radar plotting aids) or ARPA with

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[6]U.K. National Ports Council. Navigational Aids in Harbours and Port Approaches. London, England, January 1972.

[7]Bertsche, W.R., A.J. Pesch, et al. Study of the Performance of Aids to Navigation Systems, Phase I, An Empirical Model Approach. Report Number CG-D-36-78, U.S. Department of Transportation, U.S. Coast Guard, July 19, 1978.

[8]Ibid.

TABLE 4. TYPICAL EQUIPMENT ACCURACY/ERRORS

EQUIPMENT	ACCURACY/ERRORS
Gyro input to repeaters and display	$\pm$0.3 degrees
Display range accuracy (including interpretation)	$\pm$1 percent of scale
Display bearing accuracy (including interpretation)	$\pm$3 degrees near center to $\pm$1 degree near periphery
Loran-C position	$\pm$0.1 nautical miles
RDF bearing	$\pm$3 degrees
Speed log	$\pm$0.1 knot
Racon	Same as display range and bearing

a navigation option. Combinations of the levels of each variable were exercised across three normal approaches to the deepwater port complex and one approach in which ownship's navigation information was significantly degraded. The detailed description of scenarios is presented in Section 3.3.

3.2.1 Bridge Personnel Organization

Twelve subject teams were employed in the experiment. All teams consisted of VLCC qualified masters and watchstanding mates. Two different types of bridge organizations were identified and incorporated into the research as an experimental variable. Subjects who had received formal bridge team training or who are employed by a company which practices formal bridge team organization were classified as a "team organization." These subjects used specific procedures for the planning and conduct of their bridge tasks. They also employed methods of checking each other's work during the conduct of their own tasks. Each team, however, maintained numerous characteristic differences, perhaps as a result of different company policies and individual personalities. It could be concluded from observations that procedures employed in the true team concept were most evident when the master and mate were comparably experienced or had worked together previously.

All other bridge organizations exhibited during the simulation were considered a "traditional organization." In some instances, masters and mates had worked together previously; in most instances, they had not. None had received formal bridge team training, nor did they use procedures associated with formal team training courses such as radar parallel indexing.

The bridge organization variable was introduced into the experiment to examine the effect of bridge procedures on display enhancement effectiveness. One-third of the subject groups consisted of formally organized bridge teams. This was believed to be approximately representative of the potential user population since team trained crews will operate tankers for the two largest shareholders in the LOOP venture and would be expected to enter other proposed Gulf of Mexico deepwater ports. Because performance differences were expected to result between bridge team organized subjects and traditionally organized individuals, the experimental analysis was structured to examine the interaction effects between organizations when they used each different display. Further discussion of subject selection is presented in Section 3.4.

3.2.2 Navigation Display Enhancement

The second variable examined during the simulation was the effect of easily implemented navigation enhancements on the reduction of risks associated with approaches to an offshore deepwater port. Four levels of this variable were selected as representative of currently available technology. The following paragraphs describe each display enhancement and explain its role in the simulation experiment.

Radar. Since all vessels of the size considered in this study are required to have radar equipment installed and operating, the baseline navigation system includes a display which presents radar contact range and bearing information (Figure 4A). The radar display along with simulated loran, RDF, and Fathometer data formed the baseline navigation system for approaches to a deepwater port. A racon located on the LOOP complex was also available as a baseline navigation aid. This baseline system provided sufficient navigation information for the characteristic approach of a VLCC to a deepwater port under poor visibility conditions. Accuracy consistent with radar and all other navigation equipment was simulated.

Radar with Racons (Radar/Racon). The first level of navigation system enhancement was the introduction of two additional racons on oil rigs adjacent to the north/south safety fairway. The purpose of the added aids was to provide identifying features which readily isolated key oil rigs from the large number of radar contacts in the area and provided positive identification of the rigs to enhance their use as navigation aids. An example of the appearance of a racon on radar is presented in Figure 4B.

Placement of the two racons was determined by the Coast Guard as a feasible installation for LOOP. The added racons were generally representative of a number of electronic aid options which would provide a positive point of reference to augment radar. Accuracy consistent with both radar and racons was simulated.

Automated Radar Plotting Aids (ARPA). Several radar plotting aid formats are available and are in general commercial use today. Generically, they process information with respect to the radar presentation and display representative motion of objects and/or the risk of collision with ownship. One ARPA display format (Figure 5A) was selected for evaluation to determine its usefulness as an enhancement of the navigation process. Positive effects of the display might suggest increased use of ARPA displays for navigation assistance in the contact conditions, normally found near offshore ports.

The selected display presents moving objects as course vectors with a length controlled by the operator to show future position. Objects are manually acquired and automatically tracked. Their range, true bearing, true course, true speed, and closest point of approach are displayed. Accuracy consistent with ARPA systems was simulated.

ARPA with Navigation Option (ARPA/NAV). Another commercially available display is a navigation option for use with ARPA equipment. A channel outline or

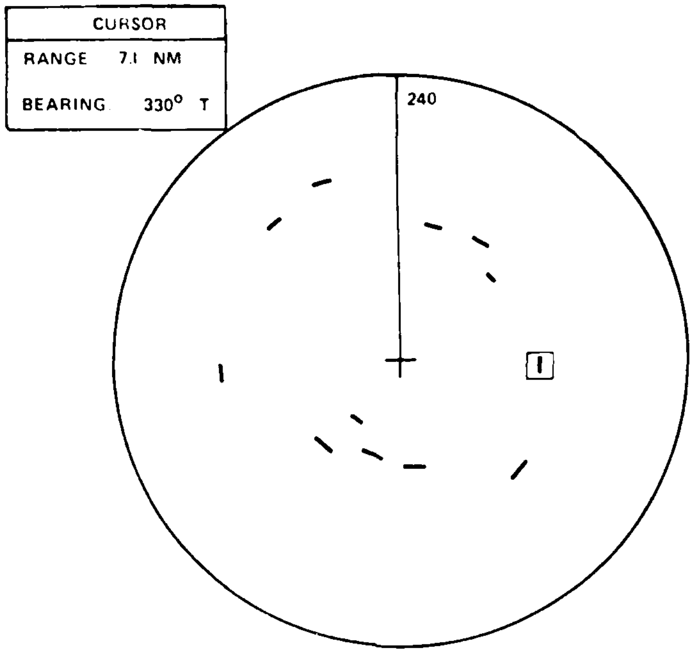

FIGURE 4A. REPRESENTATIVE RADAR DISPLAY

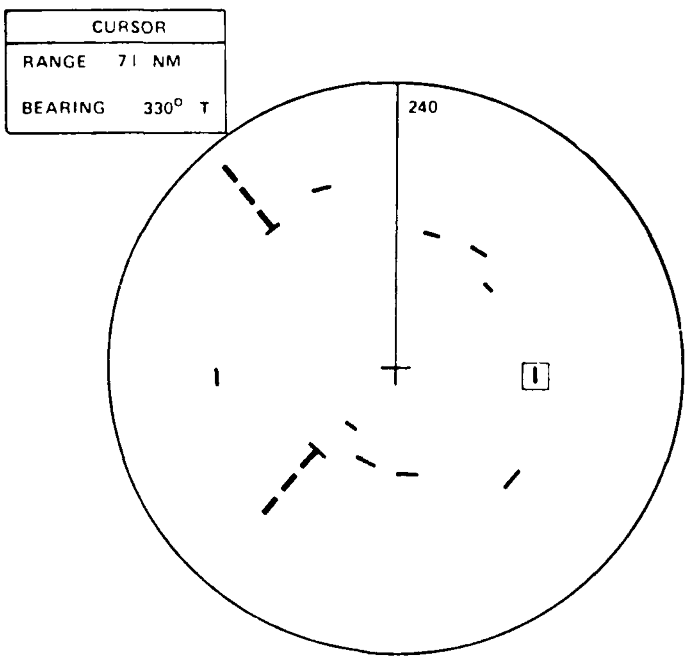

FIGURE 4B. REPRESENTATIVE RADAR DISPLAY WITH RACONS

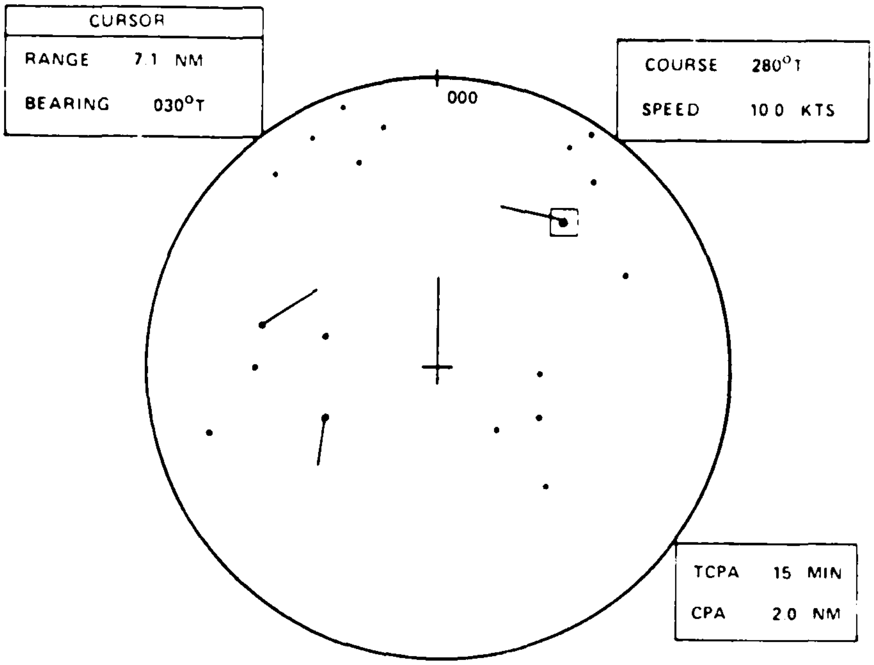

FIGURE 5A. ARPA COURSE AND SPEED VECTOR DISPLAY

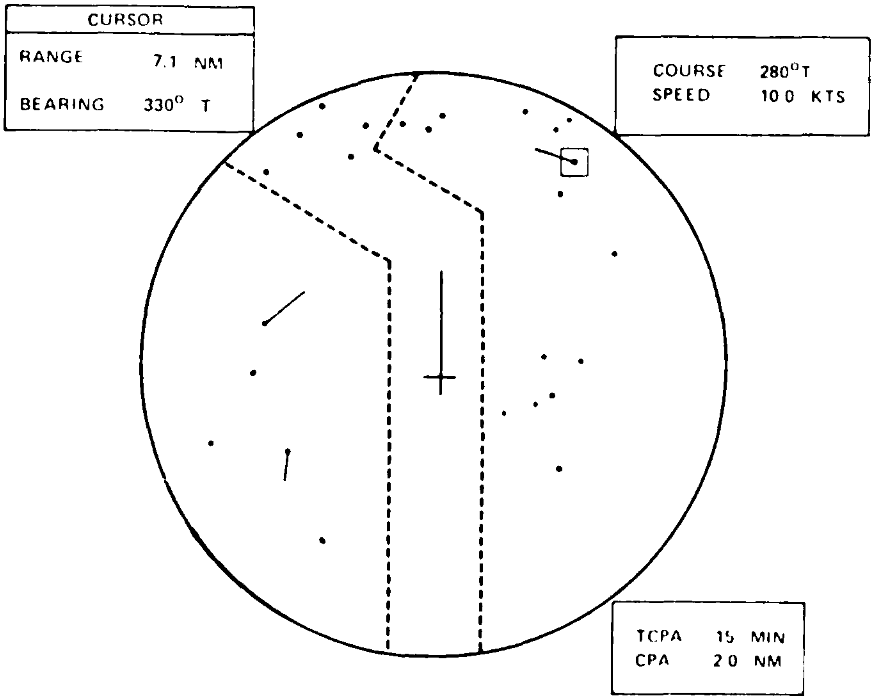

FIGURE 5B. ARPA WITH NAVIGATION DISPLAY OPTION chart display is superimposed over the ARPA display to indicate the position of the vessel relative to it (Figure 5B). Normally, the display is oriented to the ship's geographic position using an object on radar or an external navigation system for alignment. In this way, the position of ownship with respect to the surrounding area can be readily determined. The display to be used in the simulation program is aligned from a radio aids to navigation system such as loran C. The purpose of this navigation enhancement was to determine the ability of simple graphic displays to mitigate navigation hazards by providing the vessel operator with another source of information correlation. Accuracy consistent with both the radio aids to navigation system and the ARPA/NAV system were simulated.

3.3 SCENARIO DESIGN

To create a realistic setting for the simulation experiment, and one in which approach procedures, facility operations and physical characteristics are already well defined, the LOOP operating area was chosen as the basis for the investigation. LOOP is currently the only active deepwater port project in the U.S. and is scheduled to begin operation within the near future. It was, however, an objective of this project to provide findings applicable to other ports, as well. As a result, specific attempts were made both in the design of the scenarios and the conduct of the experiment to elicit conclusions which are relevant not only to the LOOP facility but to near inshore ports or offshore ports in other areas.

Four unique scenarios were designed primarily from the results of the presimulation interviews with VLCC masters. Each scenario required up to 2 hours of simulation time to complete. Rationale for ownship's starting position and the introduction of traffic and environmental factors is presented with the description of each scenario.

3.3.1 Landfall Approach Scenario

The landfall approach scenario was designed to examine the transition from open sea operation to the approach and transit of a deepwater port safety fairway. The scenario shown in Figure 6 depicted the end of a voyage from the Yucatan or Florida Straits direct to the north/south safety fairway of LOOP. A course of 305 degrees true was laid on the charts to reflect the movements of ownship from midnight local time to the 1050 start of the simulation. Ownship was initially at 16 knots, 80 rpm, having just maneuvered to give way to a traffic ship outbound from the northeast. The simulation started with ownship on a heading of 000 degrees true as a result of maneuvering from this "traffic ship close aboard." Another ship was downbound in the east/west safety fairway. This "traffic ship crossing" was introduced into the experiment to permit the option of a higher CPA or passing astern of a stand-on vessel at the expense of not entering the north/south safety fairway at its entrance. The alternative was intended to reveal subjects' regard of the overall safety fairway scheme.

The wind for the scenario was from the southeast at 25 knots. There was a northwest current of 2 knots. Poor visibility was simulated. Subjects were instructed to approach and enter the north/south safety fairway in transit to the deepwater port complex.

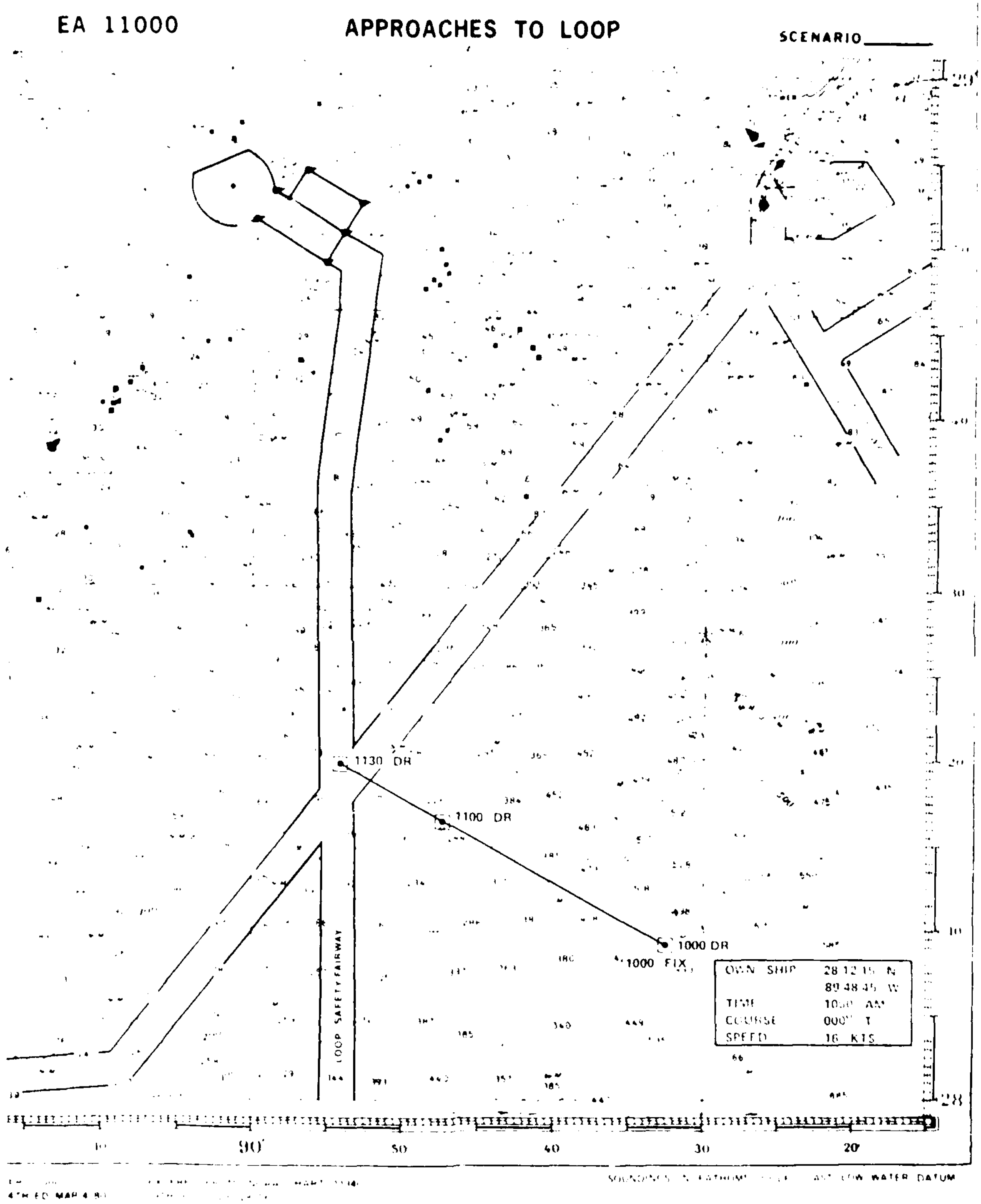

FIGURE 6. LANDFALL APPROACH SCENARIO

3.3.2 Coastwise Approach Scenario

The coastwise approach scenario was designed to examine how masters might transit to a deepwater port complex from a location which would make the use of safety fairways inconvenient or uneconomical. In this scenario, perceived benefits of circumventing the safety fairways were negated somewhat by increased risks from traffic avoidance, the requirement to steer a course through or around charted drilling rigs, and the uncertainty of uncharted structures located within the oil lease blocks.

The scenario shown in Figure 7 depicts a transit from the east, past Southwest Pass, to the LOOP complex. A 235-degree true course was laid on the charts to reflect the movements of ownship when passing abeam the Southwest Pass Light. Ownship was initially at 16 knots, 80 rpm on a heading of 235 degrees true. There were two traffic ships visible on the radar or ARPA and a number of rigs ahead. A "traffic ship close aboard" was inbound to Southwest Pass in the east/west fairway. This ship would remain the giveway vessel if ownship's course were maintained or altered to enter the safety fairway southbound. If ownship's course were changed to the north, a vessel outbound from Southwest Pass would become the "traffic ship close aboard." As revealed in the subsequent analysis of performance, the derivation of three independent strategies for the coastwise approach caused both of these vessels to come close aboard as anticipated.

Ownship was originally positioned within the scenario so that no one approach route appeared highly preferential. Rigs were located dead ahead of ownship, and it soon became apparent to each subject that he would either have to (1) sail to the south staying within the safety fairway, (2) sail to the south then to the west, keeping just outside the rigs, or (3) sail to the north then to the west through the rigs. If he chose to transit to the south outside the rigs as was hypothesized, he would encounter a "traffic ship crossing" near the end of the voyage at the north/south safety fairway. This crossing traffic was introduced to examine subjects' tradeoffs between CPAs to traffic and the relative angle with which they would enter the safety fairway. It was hypothesized that otherwise normal CPAs might be sacrificed to minimize the fairway entrance angle.

The wind for the scenario was from the southeast at 25 knots, with a northeast current of 2 knots (same as for all approaches). Again, poor visibility was simulated. Subjects were instructed to make an approach to the north/south safety fairway and proceed toward the precautionary area to meet the LOOP mooring master.

3.3.3 Mooring Master Pickup Approach Scenario

The mooring master pickup approach scenario was designed to examine how masters might approach the mooring master pickup point, how well they could maintain their position in the event the mooring master's arrival was briefly delayed, and what contingencies would be expected (e.g., anchoring, extended station keeping, returning to sea) if the mooring master delay was extended.

The scenario shown in Figure 8 depicts the end of a northerly transit up the north/south safety fairway to a point approximately 15 miles from the mooring master pickup point which is at the eastern boundary of the LOOP precautionary area. The approach initially requires position and speed determination, then course keeping and slowing to arrive at the pickup point on schedule. When it is indicated

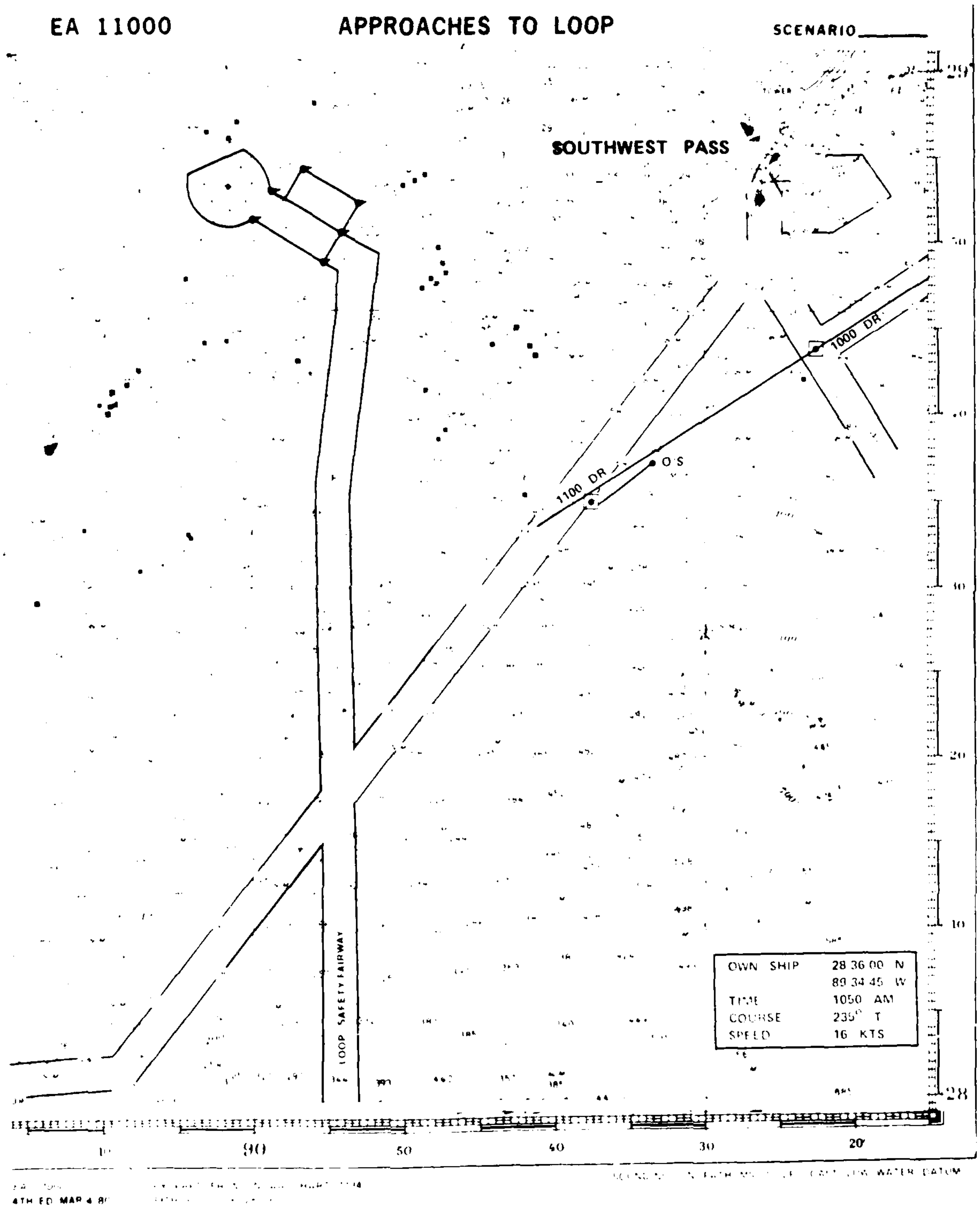

FIGURE 7. COASTWISE APPROACH SCENARIO

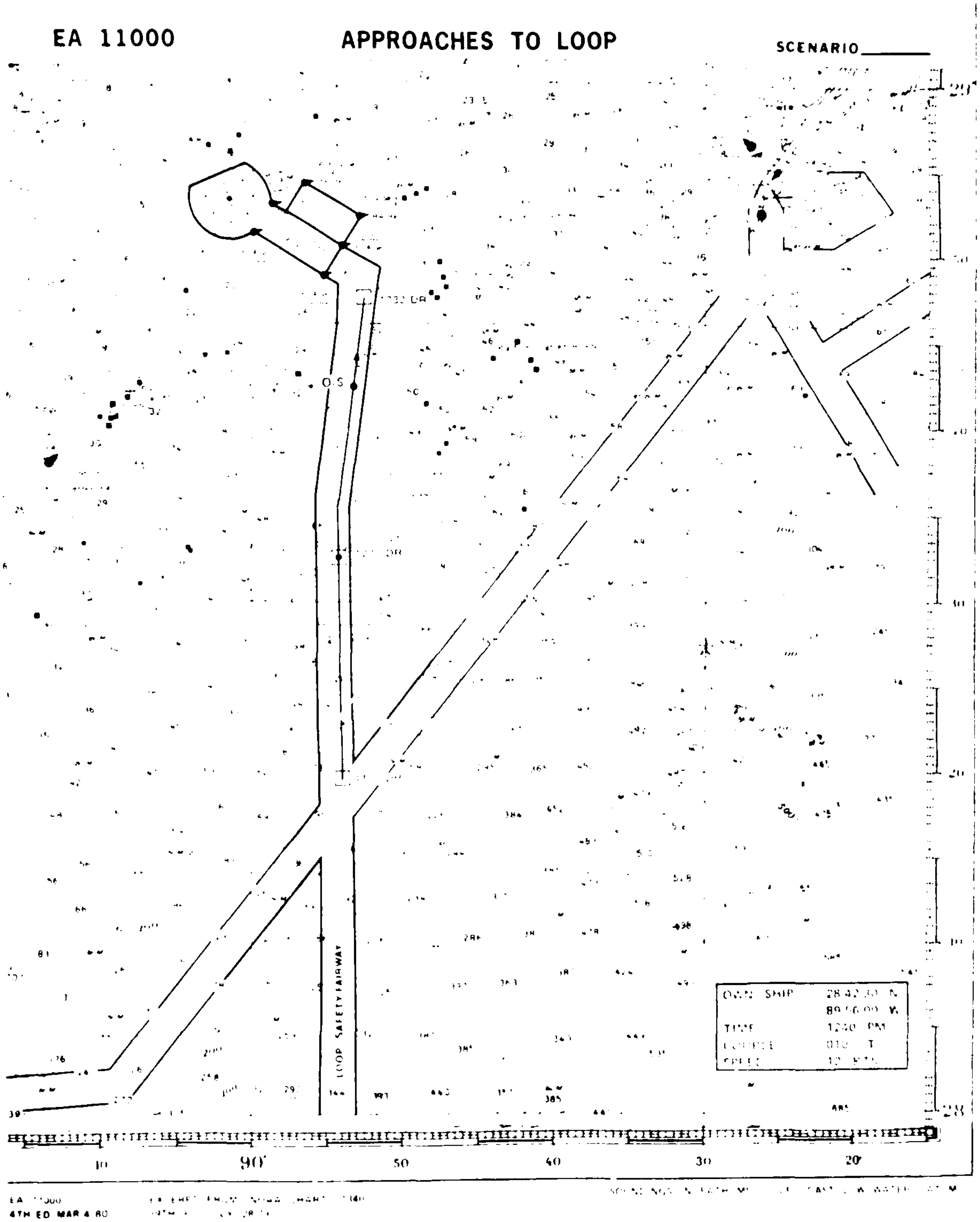

FIGURE 8. MOORING MASTER PICKUP APPROACH SCENARIO

that the mooring master has been delayed, the subject must station keep, anchor, or return to sea.

Notification of the mooring master delay was methodically introduced to permit a comparison between subject responses. The subject was first informed of an approximate 1 hour delay when he was within 30 minutes (1 to 2 nautical miles) of the scheduled pickup. If the subject elected to continue slowing to further delay arrival at the pickup point, or if he decided to station keep at the pickup point, he was informed after another 30 minutes that the delay had been extended for several more hours. This, it was hoped, would promote a desire to anchor, steam back down the fairway, or extend his station keeping. With a 2 knot crosscurrent and substantial wind effect, both the original and subsequent decisions of the subjects were of paramount interest to the research. The analysis addresses both the subjects' decisions and how well they accomplished their goals.

A 010 degrees true course was previously laid down on the chart to reflect the movements of ownship up the north/south fairway. Ownship was initially at 12 knots, 60 rpm on a heading of 010 degrees true. There was no traffic within the immediate area although ships were at anchor inside the designated LOOP anchorage. The mooring master boat was not visible on the radar or ARPA display.

The wind for the scenario was again from the southeast at 25 knots, with a northeast current of 2 knots. Subjects were instructed to make the approach to the mooring master pickup point and to be sufficently slowed to bring him onboard at 1330 local time.

3.3.4 Degraded Dead Reckoning Approach Scenario

The degraded dead reckoning (DR) approach scenario was designed to simulate a realistic landfall situation with the potential for promoting navigational disorientation. Of primary interest was the possibility of a master being lured into false navigating confidence as a result of bogus rig locations and patterns presented on the radar or ARPA display. In effect, the scenario was designed to introduce ownship into the lease blocks at a location other than that indicated by the previous DR. To accomplish this with minimum suspicion on the part of the subject, this scenario was administered at the end of all runs; after maximum confidence in the experiment had been achieved. Further, because no other erroneous information other than the DR was desired, subjects were told that their loran was inoperative; but that they still had their other navigational equipment (i.e., Fathometer, radar, RDF, etc.). In the scenario, ownship was placed approximately 20 nautical miles southwest on the same RDF bearing and at a relative comparable depth. A slow moving fishing boat was placed ahead at a location comparable to the charted rig.

This scenario which is shown in Figure 9 depicts the end of a transit from either the Florida Straits or Yucatan. A dead reckoning track of 306 degrees true had been laid down on the charts to reflect the intended track for approximately 12 hours. Overcast skies precluded celestial navigation for the past 24 hours, and loran positions could not be plotted due to equipment malfunction. Ownship was initially at 16 knots, 80 rpm, heading 305 degrees true. There was a stationary return on the radar or ARPA display bearing 330 degrees true at a range of 14 miles. It was believed to be the southwestern most rig of a large group to the east of the LOOP complex. The wind for the scenario was again from the southeast at 25 knots.

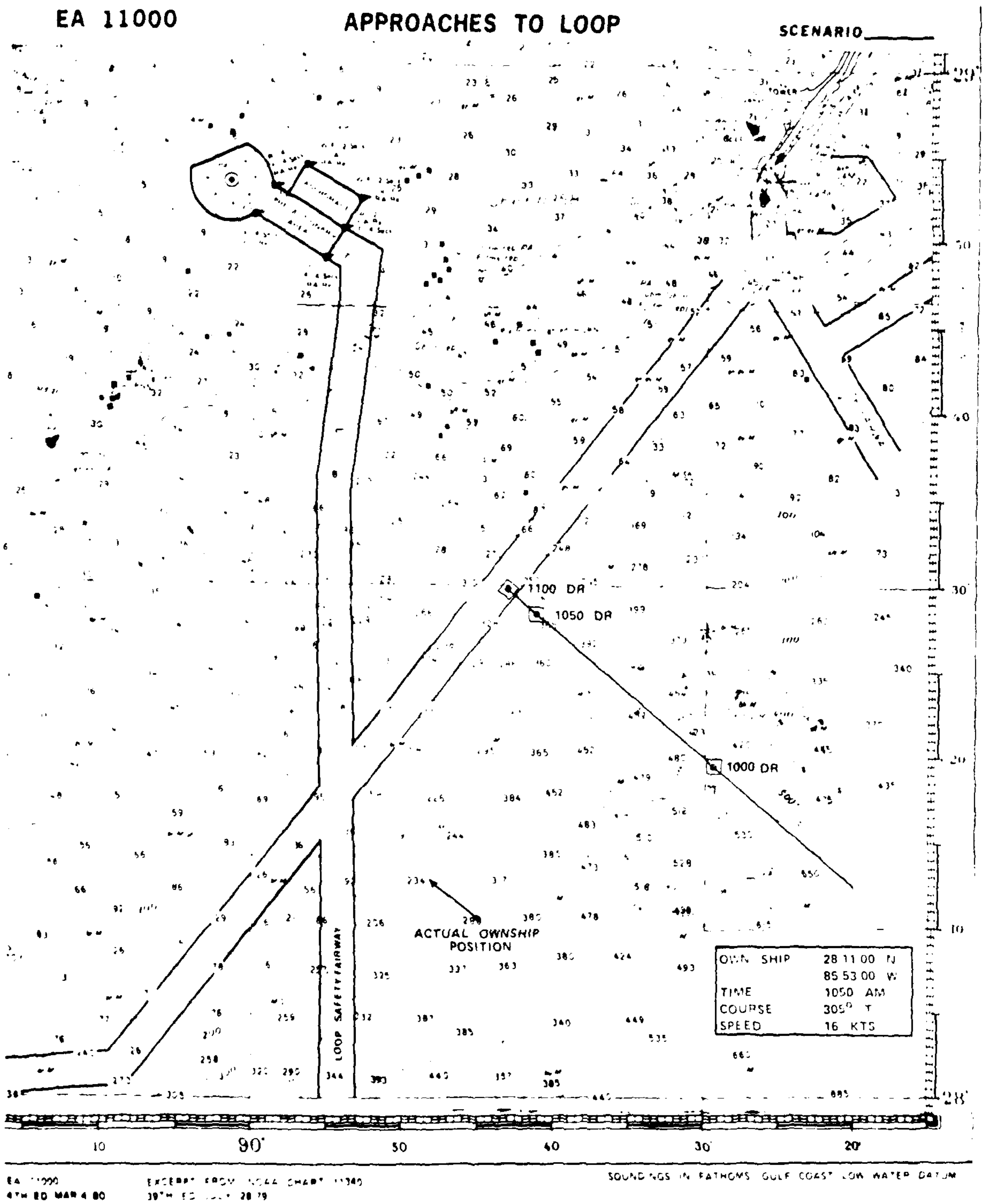

FIGURE 9. DEGRADED DEAD RECKONING APPROACH SCENARIO

Again there was a northwest current of 2 knots. Poor visibility was simulated. Subjects were instructed to make the approach and enter the north/south LOOP safety fairway.

3.4 SUBJECT SELECTION

The deepwater port simulation experiment used twelve subject teams consisting of licensed masters and mates who had operational experience aboard VLCCs. Subjects were selected by availability to represent a cross section of vessel operators likely to use the LOOP. Of these, four groups were masters and mates who had formal bridge team training (subjects 1 through 4). Seven of the remaining eight traditional groups were U.S. licensed. Subject profiles were compiled which describe the subjects' background including the amount of licensed deck officer experience he has had, the largest vessel he has piloted and his previous simulator experience. The following is a summary of these profiles:

Subject 1. This team consisted of two team-trained Italian subjects who both have unlimited masters licenses. Each captain had extensive experience with 25 years as a licensed deck officer. Both masters are graduates of the Italian Nautical Institute and have used the ship simulators for shiphandling training at Delft, Genova, and Grenoble.

Subject 2. This team consisted of two British deck officers from a major oil company. The master had previously piloted a 340,000 dwt oil tanker. Both subjects had previous ship simulator experience at Southampton.

Subject 3. This British master had over 20 years of licensed deck officer experience and both he and his mate were team-trained. The largest vessel he had piloted was a 272,000 dwt VLCC. He had extensive ship simulator training at Grenoble, Southampton and La Guardia.

Subject 4. This Italian master had 16 years of licensed deck officer experience and is team-trained. The largest vessel he had piloted was a 240,000 dwt VLCC. He is a graduate of the Italian Nautical Institute and had used the ship simulators in Genova and Southampton.

Subject 5. This master had considerable VLCC and Gulf coastal experience over a 30-year career. The largest vessel he had piloted was a 400,000 dwt VLCC. He had used the ship simulators at Grenoble and La Guardia.

Subject 6. This master had 14 years of licensed deck officer experience. The largest vessel he had piloted was a 260,000 dwt VLCC. He had no prior ship simulator experience.

Subject 7. This master had 12 years of licensed deck officer experience. The largest vessel he had piloted was a 225,000 dwt VLCC. He had no prior ship simulator experience.

Subject 8. This master had 17 years of licensed deck officer experience with 25 years of sea time. The largest vessel he had piloted was a 265,000 dwt VLCC; he had no prior ship simulator experience.

Subject 9. This master had 27 years of licensed deck officer experience and his mate had 16 years of experience. Each had piloted a 220,000 dwt oil tanker in Far Eastern, European, and U.S. waters. Neither had prior ship simulator experience.

Subject 10. This master had 16 years of licensed deck officer experience. The largest vessel he had piloted was a 265,000 dwt VLCC. He had been a subject on the Computer Aided Operations Research Facility (CAORF) ship simulator.

Subject 11. This master had 12 years of licensed deck officer experience. The largest vessel he had piloted was a 265,000 dwt VLCC. He had participated in various maritime training programs; however, he had no prior ship simulator experience.

Subject 12. This master had close to 10 years of licensed deck officer experience. The largest vessel he had piloted was a 265,000 dwt VLCC. He was a subject on the CAORF ship simulator.

When the subjects arrived at the Eclectech Associates simulator, they were administered a structured course and given the opportunity to maneuver the vessel through a trial scenario not related to LOOP. This orientation familiarized them with the arrangement and operation of bridge equipment, the simulated ship's handling characteristics and the helmsman's proficiency.

3.5 SIMULATION

There are a number of possible sources of empirical observations on the relationship between stimulus conditions and human performance. They include the real world, simulation and laboratory. The real world obviously contains the relationships of interest in all their complexity and validity; but equally obviously, extensive data collection in the real world is difficult, expensive and possibly dangerous. A more basic limitation to such a method is the unamenability of the real world to experimental control. The alternatives have been proven through research to be both practical and valid as long as fundamental principles are applied. Each subject was assigned seven runs. These included two each of the landfall approaches, coastwise approaches, and mooring master pickup approaches. The seventh scenario for each subject was the degraded dead reckoning approach. This scenario was always last to avoid affecting the master's confidence and possibly his performance in other scenarios. When a subject repeated a scenario, it was with a different navigation display enhancement. Each mooring master pickup approach scenario was run as a continuation of each landfall and coastwise approach scenario, and thus it immediately preceded them and contained the same display enhancement. The order in which subjects experienced their first six scenarios was randomized. To the greatest extent possible, each scenario and each display enhancement appeared in every order an equal number of times. The statistical application to accommodate this design is presented in Section 4.

Simulation as a research methodology is uniquely able to bring components of the real world into a controlled experimental situation. In analyzing a complex situation, it is possible to examine both the major effects within simulated variables as well as the interaction between variables. This, of course, requires a well structured experimental plan, properly designed, and reliably executed simulation, and appropriately selected measures of performance and statistical analysis.

The experiment required extensive preplanning to ensure all of these.

3.5.1 Description of the Experimental Design

The experimental design is shown in Figure 10. It is the result of accommodations to the number of levels of variables to be examined, the logistics of eliciting participation by qualified subjects, and constraints of the statistical analysis for measures of performance. The order of presentation of enhancements was randomized while exposure to each scenario was controlled.

The design enabled an analysis of performance due to the major effects (e.g., navigation display enhancement or bridge personnel organization) as well as an analysis of performance due to the interaction between them.

3.5.2 Simulator Facility

The simulator used in the experiment was developed at and by Eclectech Associates, Inc., to evaluate bridge displays such as those exhibited as display enhancements. Previous research by the U.S. Coast Guard and U.S. Maritime Administration has been conducted at this facility for evaluation of short range collision avoidance displays, maritime radar interrogator/transponder systems, predictor steering displays, and electronic radio aids to navigation displays.

The primary apparatus for the experiment was a Digital Equipment Corporation GT-44 computer graphics system with PDP-11/40 central processor and VT-11

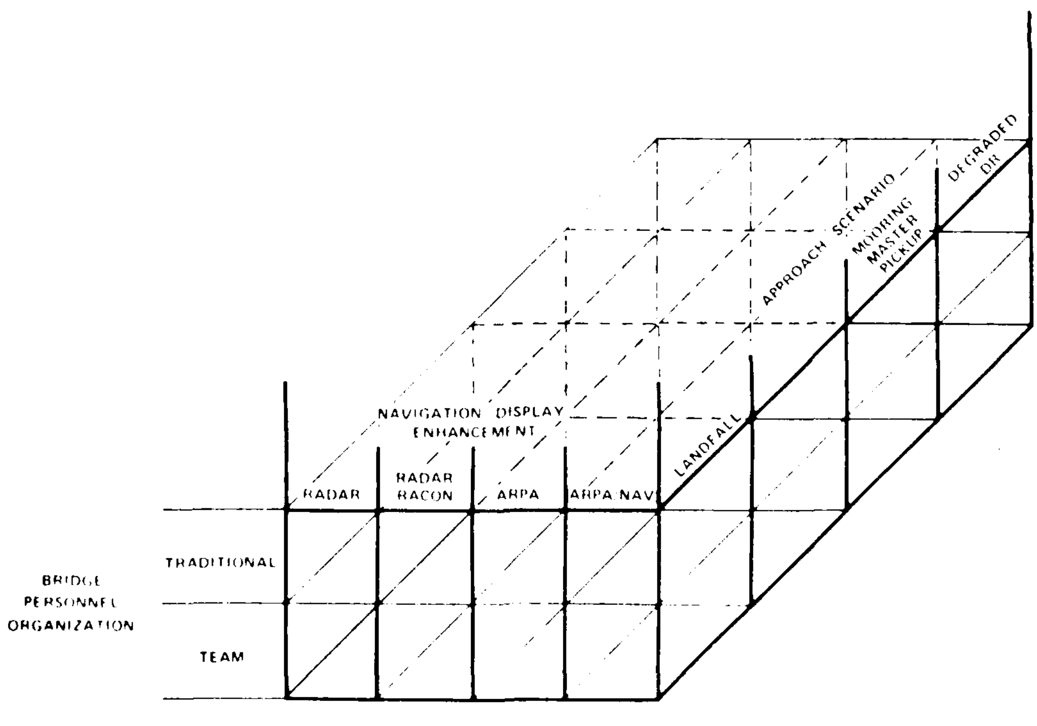

FIGURE 10. EXPERIMENTAL DESIGN

graphic generation hardware. The VR-17 CRT display is mounted in a free standing pedestal comparable to bridge installed planned position indicator (PPI) systems. It is located on the centerline of the ship and against the forward bulkhead of the bridge just below the gyrocompass repeater. The helm, engine order telegraph, rudder angle indicator, and rpm indicators are installed on a steering console, located to the right of center and also forward. This arrangement is solely for the benefit of the experiment, enabling the subject to monitor all ship control functions with minimum distraction. The facility includes a visual simulation capability which was not employed in the experiment. It is noted that without a visual scene the helmsman did not require a visual range for steering and was able to maintain course using his own console mounted gyro repeater. The simulator facility consists of:

- wheelhouse
- ship's controls
- ship's indicators
- radio aids to navigation display
- scene projection system
- PDP 11/40 with requisite interface equipment
- data reduction facility

The Wheelhouse. The wheelhouse is approximately 16 feet wide and 11 feet deep. When the visual scene is used, it can be viewed through all windows for the presentation of day, night, and intermediate scenes. Additional facilities include a chart table with chart stowage. The lighting in the wheelhouse can be varied in night operating conditions.

Ship's Controls. The control mechanisms found in the bridge simulator are tied directly to the PDP 11/40 computer, providing the proper inputs for ship's controls with resultant ship's motion incorporated in the visual image. These control mechanisms include the following:

- a ship's wheel and helm unit
- an engine order telegraph which provides control of the ship's speed both ahead and astern. Propeller rpm is determined by ownship characteristics programmed into the computer

Ship Indicators. The indicators available to provide information to the pilot include:

- a gyrocompass overhead repeater and console mounted repeater providing indications of ownship's heading as transmitted by the computer
- a shaft rpm indicator that shows the shaft rpm transmitted by the computer
- a rudder angle indicator
- a rate of turn indicator
- a ship's clock which has been modified to show scenario time

Radar and Navigation Display. The electronic bridge display unit is capable of presenting radar, ARPA, and a variety of other information displays to the watch officer.

The PDP 11/40 Computer. The PDP 11/40 computer provides dynamic signals for the electronic bridge display or visual system. These signals are modified by the appropriate program to reflect ownship's characteristics including maneuverability, visibility, hydrodynamic influences, and individual scenario conditions.

Data Reduction Facility. The computer facilities are configured to provide supporting data reduction and analysis with a minimum of data manipulation or conversion.

3.6 DATA COLLECTION

Data from the experiment was collected during the simulation by observers on a structured "observer sheet," as the result of subject questionnaire responses, and automatically by the simulator computer. Additionally, some information such as control commands and the type of fixes performed were manually input into the computer during the simulation. All ship position and ship status information was recorded by the computer at 60-second intervals. Once unique strategies were determined, it was possible to compute a mean strategy track. Perpendicular lines were then inscribed along this mean track, extending out until they intersected all other tracks within the strategy. Wherever a perpendicular crossed a trackline, the data collected at 60-second intervals closest to the perpendicular were retained for comparative analysis. In the case of measures requiring a frequency count (i.e., frequency of radar fixes, engine orders, etc.), events were accumulated and recorded at each perpendicular. All closest point of approach (CPA) measures to stationary objects and traffic were computed after the run as a result of the track made good.

Data collected and/or computed during all runs are shown in Table 5. While all of this data was available to the researchers for analysis, only specific measures were selected for each scenario and strategy. This selection of measures and their subsequent statistical analysis is discussed in the next section.

TABLE 5. DATA COLLECTED FOR DEEPWATER PORT EXPERIMENTAL ANALYSIS

TRACKKEEPING/ MANEUVERING	SAFETY	WORKLOAD AND EQUIPMENT UTILIZATION	ACCEPTANCE AND VALIDATION
Automatically recorded every 1 minute (transcribed to data lines during analysis)			
True position Gyro heading True course Drift angle (computed) Turn rate (computed Speed over ground Rudder angle Engine rpm	CPAs to traffic (computed) CPAs to rigs and hazards (computed)	Display orientation Display range scale Target range bearing used	
Manually recorded each event			
Rudder commands Course commands Engine orders		Display used LORAN fixes RDF fixes Radar fixes Dead reckoning computed Unique comments	
Recorded by interview, questionnaire, or observation			
Strategy Unique comments	Procedural Compliance Consequences of disorientation Unique comments		Critique of displays Self appraisal Simulation fidelity Deepwater port operation fidelity

Section 4

DATA ANALYSIS

4.1 DESCRIPTION OF THE ANALYSIS PROCESS

To adequately describe and quantitatively compare runs performed during the deepwater port approach experiment, a variety of analysis techniques were employed. Observations of the research team made during each simulation were recorded and compiled on structured run profile sheets. These sheets detailed, among other things, planned and actual strategy, effects of traffic, navigation methods, and a description of the resulting track made good. A summary of these observations was published as an interim project report.[9] They provided a guide for the selection of performance measures to be quantitatively analyzed as well as a method of identifying and categorizing different strategies within each scenario.

In effect, the analysis of observations made during each simulation enabled a determination of how that simulation should be measured. Observation data were also used after the quantitative analysis to explain unique occurrences or behaviors and to check the effectiveness of the particular measure. For example, if from the quantitative data it was determined that subjects seldom use RDF under certain conditions, the observation would not only confirm that the RDF was not used, but might explain why it was not used. Observation data for interpreting quantitative data employed extensively in the data analysis, and many of the conclusions of the study are derived through this chain of evidence.

Questionnaries were used to elicit additional information about what the subject had planned to do and what he actually accomplished (or thought he accomplished). Questionnaire results were also used in compiling the run profile sheets and, as such, provided valuable insight into what had actually occurred during the simulation. Some questionnaire results related to the subjects' perceptions of the display enhancements and the simulation in general. These results are discussed along with recommendations of the subjects in Section 4.6.

A quantitative analysis was conducted on the performance measures selected for each scenario and strategy. These measures, the rationale for their selection, and the statistical tests applied to them are discussed by scenario and strategy in Sections 4.2 through 4.5.

4.1.1 Statistical Applications

Design of the deepwater port experiment attempted to control the order in which scenarios were administered and maintain equal sample sizes of subjects using different display enhancements. Subjects, however, were permitted to select their own strategy for each approach, and these strategies themselves were of major interest to the research. Because the strategies differed both in tracks made good

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[9] Eclectech Associates, Inc. Preliminary Observations and Sample Data Analysis for a Simulator Study of Deepwater Port Potential Tanker Problems in Poor Visibility. U.S. Department of Transportation, U.S. Coast Guard, July 1980.

and often encounters with different rigs and traffic, it was difficult to statistically compare the quantitative measures of an entire scenario.

The result is that each strategy in each scenario was analyzed individually. While this provided a thorough description of each potential deepwater port strategy, the reduced and occasionally unequal sample size somewhat limited the ability to derive statistical conclusions.

To accommodate unequal cell sizes, an analysis of variance (ANOVA) method of unweighted means statistic was chosen. This procedure is described in Snedecor and Cochran[10] and more recently by Myers.[11] It essentially treats the means of cells, allowing for some disparity as a result of the unequal samples. The analysis of variance is a two-factor design providing an evaluation of "main effects" such as the effect of bridge organization or display enhancement as well as "interaction effects" between particular organizations with particular enhancements.

The F-statistic was applied to compare two population variances. It was performed on crosstrack variance to compare the trackkeeping consistency of different groups. The results are presented graphically in Appendix A. The F-test which was used is described in Pfaffenberger and Patterson.[12]

When the test of a hypothesis produces a sample value falling in the critical region of the test, the result is identified in this report as "significant." On tables, the significant value is designated with an asterisk (*). This means the null hypothesis, that the values are similar, should be rejected, and that some other hypothesis is necessary. The probability of committing a type I error (i.e., that the null hypothesis is true but still rejected) is called the level of significance. For all statistical tests performed in this experiment, the level of significance has been chosen equal to or less than 0.10. In other words, for all measures which are indicated as "significant" in this report, there is a 10 percent possibility that the results really could have occurred by chance alone.

4.1.2 Analysis of Performance

The analysis combined results of the run profile sheets (i.e., observations, research notes, and questionnaire responses), run track plots, and statistical analysis of quantitative measures, to provide a logical "chain of evidence" from which all conclusions about overall performance could be derived. This analysis is presented in the remaining subsections by scenario. The rationale for deriving each strategy as well as its analysis is included. Each subsection concludes with an overview of findings and summary of approach performance for the entire scenario.

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[10] Snedecor, G.W. and W.G. Cochran. Statistical Methods, 6th edition. Ames, Iowa State University, 1967.

[11] Myers, J.L. Fundamentals of Experimental Design, 3rd edition. Allyn and Bacon, Inc., 1979.

[12] Pfaffenberger, R.C. and J.H. Patterson. Statistical Methods for Business and Economics. Homewood, Illinois, Richard D. Irwin, Inc., 1977.

4.2 DERIVATION OF LANDFALL APPROACH STRATEGIES

The resultant tracks of all runs in the landfall approach scenario are shown in Figure 11. The plots show the center of gravity (CG) of ownship from the starting position until the goal of each run had been achieved. Differences in track goals and their attainment are obvious in the figure. Some subjects made a concerted effort to enter the north/south safety fairway at the intersection, others were content to cut off the intersection corner, still others were intent on first handling the traffic ship then entering the fairway further north. This graphic portrayal of trackkeeping results as well as the subjects' stated intentions during the approach led the analysts to identify and categorize three unique strategies for the landfall approach scenario. All runs were grouped by strategy for the analysis of performance. Strategies are compared and discussed on an individual basis.

The mean track plus or minus two standard deviations of crosstrack variability for each strategy was computed and plotted to show how the strategies differed in their resultant approach. These plots are shown on Figure 12. The plot assumes a normal crosstrack distribution for all runs within each strategy. As a result, the center or mean track can be considered the average track for that particular strategy If the runs were normally distributed, the shaded portion of the plots would represent the area in which 97 percent of the master population would transit the waterway under similar operating conditions. It appears from the raw data that not all portions of all plots were normally distributed. As a result, some artistic license has been exercised in drawing the plots so as not to give the erroneous impression of an unsafe condition. Relatively robust statistical tests were employed. The assumption of normality should not significantly affect the results.

The most dominant strategy which appeared in the landfall approach scenario set a course for the north/south safety fairway intersection and made every effort to enter the fairway in the center or just to the right of center. This dominant strategy which occurred in 76 percent of the runs is considered most representative of the landfall approach. As a result, the dominant strategy of the landfall approach scenario is considered characteristic of anticipated deepwater port operations and is therefore the most thoroughly examined.

The remaining 24 percent of all runs is included in two secondary strategies. These are labeled secondary strategy "A" and secondary strategy "B" and are described in their respective sections.

4.2.1 Analysis of Dominant Strategy

Figure 13 shows the mean track and crosstrack variability of the landfall approach dominant strategy. The group includes a near equal number of runs using each of the display enhancements (i.e., radar, radar/racon, ARPA and ARPA/NAV), but more than twice as many subjects practiced traditional bridge organization than were team organized. The figure shows the subjects clearing the traffic ship close aboard, setting a course for the fairway intersection and entering the north/south safety fairway for a transit to right of center of the fairway.

In general, the transits were all considered safe and characteristic of prudent shiphandling. The review of postsimulation questionnaires from subjects suggests that under the conditions of visibility only a few subjects would have been hesitant to maintain full maneuvering speed. Subjects considered the shiphandling characteristics, bridge equipment, traffic encounters, and deepwater port approach requirements realistic and appropriate for the fulfillment of their prescribed objectives.

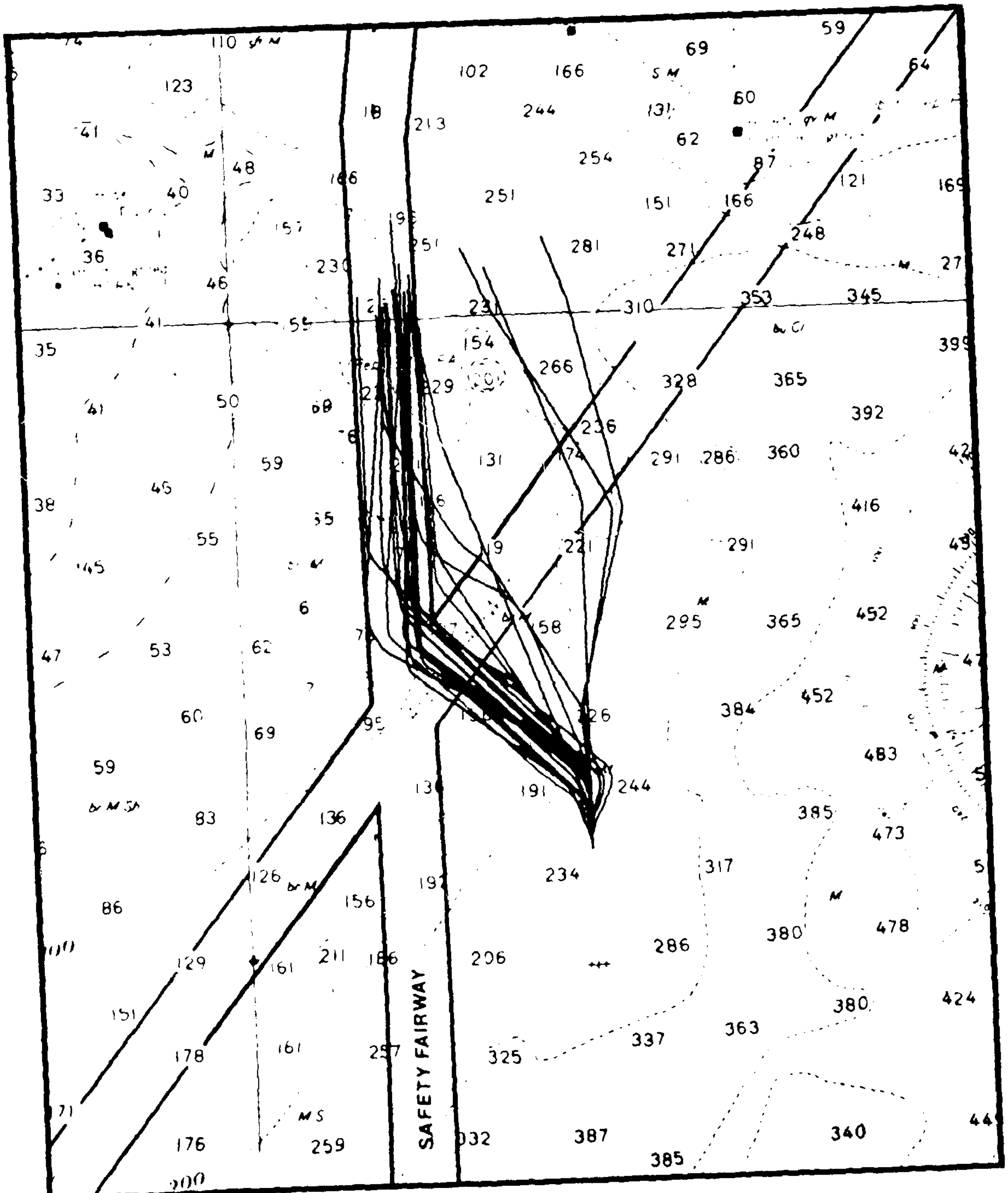

FIGURE 11. INDIVIDUAL SHIP TRACKS DURING THE LANDFALL APPROACH

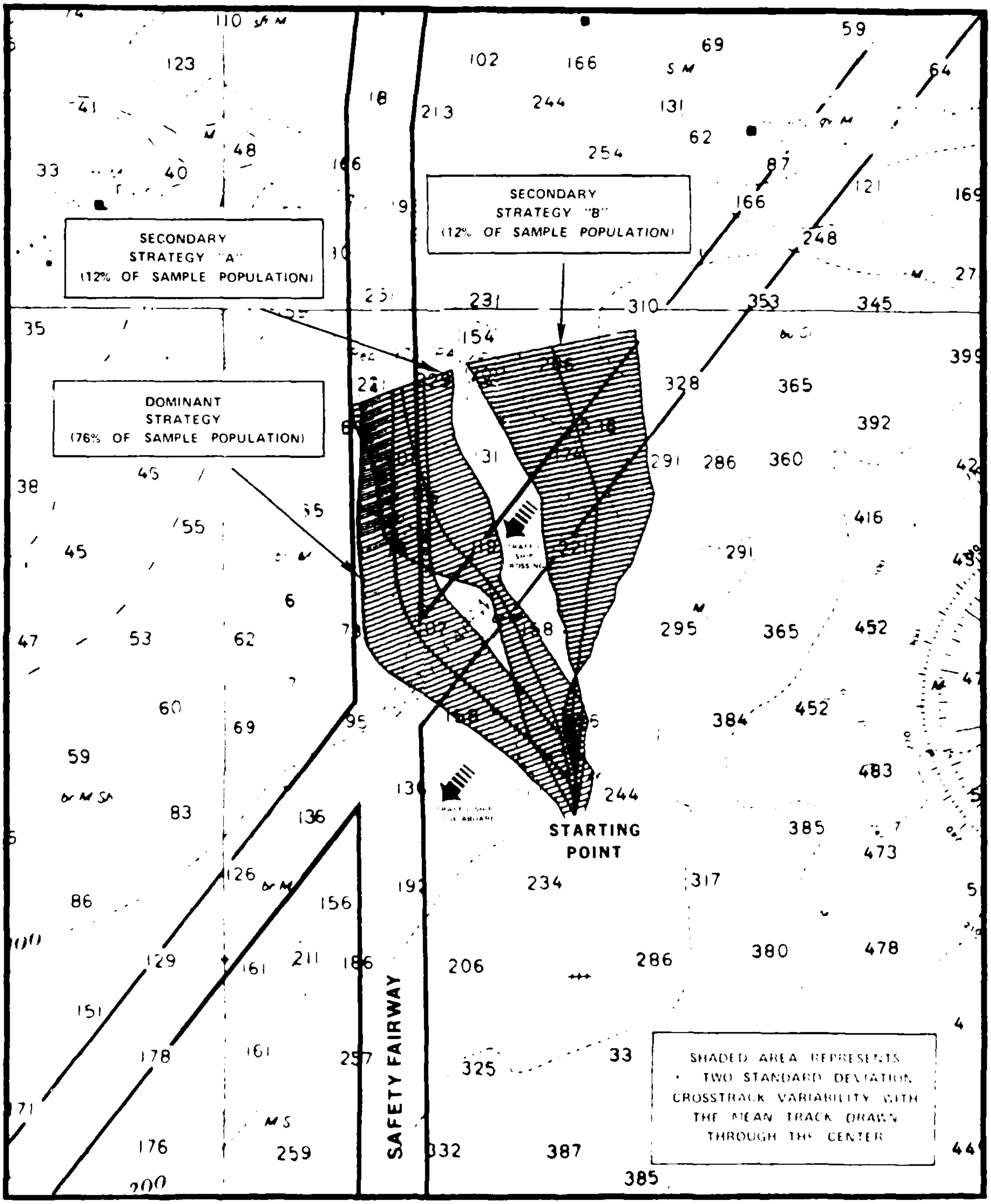

FIGURE 12. THREE STRATEGIES OF THE LANDFALL APPROACH

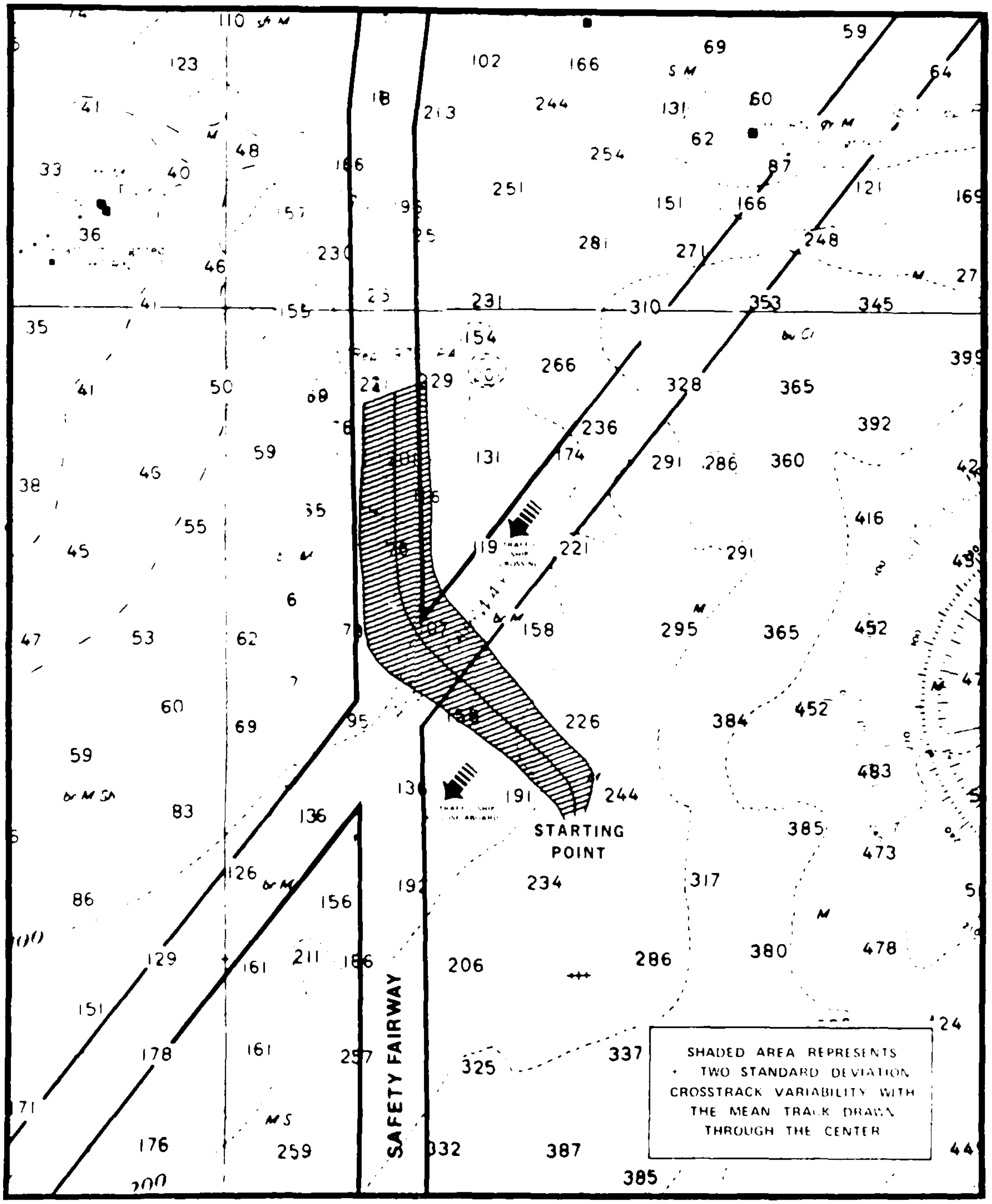

FIGURE 13. DOMINANT STRATEGY OF THE LANDFALL APPROACH

4.2.1.1 Analysis of Performance

Performance measures and the application of statistics to the dominant strategy of the landfall approach scenario are as follows:

1. Mean track
2. Crosstrack variability
3. Mean speed and rpm
4. Mean frequency of engine, rudder and course orders
5. Mean frequency of radar, loran, RDF and Fathometer fixes, and DRs
6. Mean CPA to each traffic ship
7. Lowest CPA to each traffic ship

Note: There are no rigs in the landfall approach scenario which present a potential hazard to navigation.

A two-way analysis of variance (ANOVA) was conducted to test main effects of the display enhancement and bridge organization variables, as well as potential interactions. The results which were indicated at the 0.10 level of significance are so identified in the text by the words "statistically different" or "significant difference." A detailed explanation of the significance level chosen is presented in Section 4.1

4.2.1.2 Effect of Display Enhancement on Performance

An analysis of subject performance as a function of which display enhancement they had used during the run was conducted by combining all runs of traditional and team bridge organizations. The results show some impact of display enhancement upon overall performance. First of all, all radar and radar/racon runs were combined and labeled "radar based displays." Next, all ARPA and ARPA/NAV runs were combined and labeled "ARPA based displays." For a description of these displays, refer to Section 3.2.2. Approach performance was compared between radar based displays and ARPA based displays with the intent of examining what effect computed ownship and traffic motion would have on the deepwater port approach without additional navigation aids such as racons or the ARPA navigation option. Following this analysis, a comparison of performance was conducted between individual radar, radar/racon, ARPA and ARPA/NAV displays. In the following discussion, all results are attributed solely to the effect of display enhancement.

The comparison of trackkeeping performance between radar based displays and ARPA based displays shows a significant difference in crosstrack variability (Figure A-1 of Appendix A) and some difference in mean tracks (Figures B-1 and B-2 of Appendix B). While the mean tracks and crosstrack variability were almost identical up to the fairway entrance, the ARPA based display mean was continuously further east. This difference increased as ownship proceeded up the north/south fairway until the radar based track was exactly in the center of the fairway and the ARPA based track was exactly in the center of the right half of the fairway. Crosstrack variability with the radar based displays was more than double the ARPA based displays. Table 6 (lines 1 and 2) shows no significant difference in ship control between when radar based displays were used and when ARPA based displays were

TABLE 6. SHIP CONTROL AND COURSE KEEPING –
LANDFALL APPROACH, DOMINANT STRATEGY

Variable	Strategy Mean Speed (knots)	RPM	Engine Orders	Rudder Orders	Course Orders
Enhancement Effect					
1. Radar based displays	14.2	77	0.6	4.6	4.9
2. ARPA based displays	14.3	78	0.2	8.9	4.1
3. Radar	14.6	79	0.2	5.8	5.0
4. Radar/racon	13.9	69	0.8	3.6	4.8
5. ARPA	13.9	76	0.0	5.2	4.6
6. ARPA/NAV	14.3	80	0.4	12.6	3.6
Organization Effect					
7 Traditional organization	14.6	79	0.3	8.6	4.1
8. Team organization	13.3	71	0.6	1.8	5.4
9. Radar based displays - traditional organization	14.6	79	0.3	5.3	4.9
10. Radar based displays - team organization	13.0	69	1.5	2.0	5.0
11. ARPA based displays - traditional organization	14.7	80	0.3	11.5	3.4
12. ARPA based displays - team organization	13.5	73	0.0	1.7	5.7
13. Radar - traditional organization	14.6	79	0.2	5.8	5.0
14. Radar - team organization	--	--	--	--	--
15. Radar/racon - traditional organization	14.6	79	0.3	4.7	4.7
16. Radar/racon - team organization	13.0	69	1.5	2.0	5.0
17. ARPA - traditional organization	14.6	80	0.0	7.7	3.7
18. ARPA - team organization	12.9	69	0.0	1.5	6.0
19. ARPA/NAV - traditional organization	14.8	80	0.5	13.4	3.3
20. ARPA/NAV - team organization	14.6	80	0.0	2.0	5.0

NOTE: No statistical difference at $p \leq 0.10$ level of significance indicated for any value.

used. Tables 7 (navigation workload) and 8 (hazard avoidance), lines 1 and 2, also show no differences in performance. As a result, it is suggested that those differences in performance which did occur during the landfall approach were not manifest in ship control, navigation or hazard avoidance performance; but instead appeared to have affected only trackkeeping during the approach. This finding suggests a conscious difference among subjects in their selection of tracks which can only be explained by a more detailed comparison of performance between individual display enhancements.

<u>Comparison Between Radar, Radar/Racon, ARPA and ARPA/NAV Displays.</u> In a trackkeeping comparison between when the radar and radar/racon displays were used, significantly larger crosstrack variability (Figure A-2) occurred with the radar display prior to the fairway entrance. Once inside the fairway, crosstrack variability remained small for both. Table 6 shows overall few engine orders with a resultant very consistent speed throughout the approach. Again, ship control performance was virtually unaffected by enhancement. Table 7 (lines 3 and 4) shows considerably fewer (though not statistically significant) RDF fixes when the racon was available than when radar alone was used. This indicates a trend toward using the RDF less whenever an alternate, positively identifiable, and perhaps more accurate, aid to navigation is available.

The major differences in performance between the ARPA based displays were a significantly larger crosstrack variability toward the end of the transit when ARPA/NAV was used (Figure A-3). This variability was the result of substrategies which occurred when masters entered the safety fairway. Although all masters' original strategy was to transit up the center of the safety fairway, this was revised by some at the fairway entrance. After initiating their entrance maneuver, it became apparent to these masters that they would end up to the right of center. Since as a result of the ARPA/NAV information each knew precisely where he was in the fairway and that there was no traffic ahead, each elected to revise his strategy and keep to the right side. This substrategy was not analyzed separately although its existence does suggest that when the navigation option was provided on ARPA (i.e., fairway boundaries are delineated) subjects tended to be more confident of their position and their ability to navigate within the fairway. The review of Table 6 shows considerably more (though not statistically significant) rudder orders (line 6). At the same time, Table 7 (also line 6) does show significantly fewer radar fixes, Fathometer fixes, and DRs when the ARPA/NAV information was utilized. This is additional proof of the subjects' confidence in ARPA/NAV position information. Although it must be pointed out that the frequency of loran fixes did not change, there is statistical evidence to show that the navigation option on ARPA substituted for traditional navigation methods. No significant differences in hazard avoidance (Table 8) as a function of display enhancement were identified, further suggesting [illegible] invariably safe transits for all enhancements.

4.2.1.3 Effect of Bridge Organization on Performance

An analysis of performance as a function of how the bridge team was organized and operated was conducted by combining runs of all display enhancements. For a description of bridge organizations, refer to Section 3.2.1. The results show that mean tracks differed only at the entrance to the north/south safety fairway. The traditional organization's mean track was to the east, tending to cut off the corner (Figures B-7 and B-8). At the corner, there was a significantly higher crosstrack variability (Figure A-4). On the other hand, the team organization consistently

TABLE 7. NAVIGATION WORKLOAD – LANDFALL APPROACH, DOMINANT STRATEGY

Variable	Mean Frequency of Radar Fixes	Loran Fixes	RDF Fixes	Fathometer Fixes	DRs
<u>Enhancement Effect</u>					
1. Radar based displays	8.0	4.2	0.7	1.7	4.7
2. ARPA based displays	4.1	3.9	0.8	1.5	2.3
3. Radar	6.0	3.3	1.2	1.8	3.7
4. Radar/racon	9.6	5.0	0.2	1.6	5.4
5. ARPA	5.0	4.8	0.8	2.8	4.0
6. ARPA/NAV	3.2*	3.0	0.8	0.2*	0.6*
<u>Organization Effect</u>					
7. Traditional organization	5.3*	3.4	0.8	1.1	2.9
8. Team organization	7.8	5.8	0.6	2.8	5.0
9. Radar based displays - traditional organization	7.4	3.4	0.7	1.0	4.1
10. Radar based displays - team organization	10.0	7.0	0.5	4.0	6.5
11. ARPA based displays - traditional organization	3.1	3.4	0.9	1.3	1.6
12. ARPA based displays - team organization	6.3	5.0	0.7	2.0	4.0
13. Radar - traditional organization	6.0	3.3	1.2	1.8	3.7
14. Radar - team organization	--	--	--	--	--
15. Radar/racon - traditional organization	9.3	3.7	0.0	0.0	4.7
16. Radar/racon - team organization	10.0	7.0	0.5	4.0	6.5
17. ARPA - traditional organization	4.3	4.0	1.0	2.7	3.3
18. ARPA - team organization	6.0	6.0	0.5	3.0	5.0
19. ARPA/NAV - traditional organization	2.3	3.0	0.7	0.2	0.2
20. ARPA/NAV - team organization	7.0	3.0	1.0	0.0	2.0

* = statistically different at $p < 0.10$ level of significance

TABLE 8. HAZARD AVOIDANCE - LANDFALL APPROACH, DOMINANT STRATEGY

Variable	Mean CPA to		Lowest CPA to	
	Traffic Ship Close Aboard	Traffic Ship Crossing	Traffic Ship Close Aboard	Traffic Ship Crossing
<u>Enhancement Effect</u>				
1. Radar based displays	1.24	2.86	1.02	2.00
2. ARPA based displays	1.26	2.31	1.09	1.68
3. Radar	1.23	2.91	1.13	2.33
4. Radar/racon	1.22	2.82	1.02	2.00
5. ARPA	1.25	2.29	1.18	1.68
6. ARPA/NAV	1.28	2.33	1.09	2.23
<u>Organization Effect</u>				
7. Traditional organization	1.25	2.66	1.09	2.20
8. Team organization	1.23	2.33	1.02	1.68
9. Radar based displays - traditional organization	1.25	2.93	1.13	2.33
10. Radar based displays - team organization	1.14	2.61	1.02	2.00
11. ARPA based displays - traditional organization	1.25	2.39	1.09	2.20
12. ARPA based displays - team organization	1.29	2.14	1.26	1.68
13. Radar - traditional organization	1.23	2.91	1.13	2.33
14. Radar - team organization	--	--	--	--
15. Radar/racon - traditional organization	1.28	2.96	1.25	2.43
16. Radar/racon - team organization	1.14	2.61	1.02	2.00
17. ARPA - traditional organization	1.24	2.28	1.18	2.20
18. ARPA - team organization	1.27	2.05	1.26	1.68
19. ARPA/NAV - traditional organization	1.26	2.33	1.09	2.23
20. ARPA/NAV - team organization	1.35	2.31	1.35	2.31

NOTE: No statistical difference at $p < 0.10$ level of significance indicated for any value.

entered the safety fairway closer to its center. Table 6 (lines 7 and 8) shows no significant difference between organizations for rudder orders, course orders, or speed. Table 7, however, shows that the team organization took significantly more radar fixes throughout the approach. This was also verified in the observations which revealed that the team organization was more methodical and repetitive in its performance of radar fixes.

There was no observable difference in the selection of strategies between bridge organizations. However, those individuals from among both organizations who had the most Gulf of Mexico experience tended to be the ones who traveled outside the safety fairways. There is evidence that bridge organization had the most effect upon performance during the landfall approach. To define this effect, the interaction between particular enhancements with particular bridge organizations is further examined.

4.2.1.4 Effect of Enhancement/Organization Interaction on Performance

An analysis of performance was conducted on the interaction effects between type of display enhancement used and the organization of the bridge personnel who used it. This particular analysis was expected to explain some of the more fundamental differences which were apparent in the main effects. It must be noted, however, that due to greatly decreased sample size at the interaction level of the analysis, it was more difficult to derive statistical conclusions.

In the comparison of performance between bridge organizations for personnel using radar based displays, the mean tracks were different only at the fairway intersection. Again, the team organized group maneuvered closer to the fairway center (Figures B-9 and B-10). The largest difference in crosstrack variability occurred within the first mile after entering the fairway. The traditionally organized subjects' variability was significantly less and more uniform (Figure A-5) through the entrance. Tables 6 and 7 (lines 9 and 10) show no difference in shiphandling or navigation technique as a result of bridge organization with radar and racons.

With ARPA based displays, the bridge team organized subjects had the smaller overall crosstrack variability. The greatest difference (Figures A-6, B-11, and B-12) occurred just before the entrance to the north/south fairway. The two mean tracks were generally similar except at the fairway entrance where the team organization entered closer to the fairway center. From the center, they eventually moved to the right half of the fairway; whereas the traditional group cut the corner by entering the fairway on the right and remained on the right all the way toward the complex. Again, no difference in ship control or navigation workload was indicated.

Lines 13 through 20 of the tables show the basic interactions between each enhancement and each bridge organization. They also provide insight into what actually occurred during the landfall approach and what ramifications this performance could have on a deepwater port approach in general. No team organization used only the radar display in this strategy, however, conclusions about the radar/racon utilization can be made. Major differences in performance gleened from the review of interaction track plots and Tables 6 through 8 are that regardless of the display used, traditionally organized bridge personnel tended to enter the fairway along the right side and with a more gradual maneuver. Consequently, they cut across the fairway corner. The traditional group was more consistent among themselves in this behavior. Team organized personnel were more individual in their goal, some choosing a large course change, entering the fairway in the center, then maneuvering to the right.

Overall, there were no significant differences in CPA to traffic ships for either organization or display enhancement. In fact, it is noteworthy that exemplary performance was demonstrated for all traffic avoidance (there were no oil rigs close aboard in this scenario). As shown in Table 8, the following prevailed for each and every variable tested:

- To the traffic ship close aboard:
  a. Mean CPA was always greater than 1 nautical mile.
  b. Lowest CPA was always greater than 1 nautical mile.
- To the traffic ship crossing:
  a. Mean CPA was always greater than 2 nautical miles.
  b. Lowest CPA was always greater than 1.5 nautical miles.

4.2.2 Analysis of Secondary Strategies

Approximately one quarter (24 percent) of all subjects in the landfall scenario chose to approach the deepwater complex without an explicit goal for where to enter the north/south safety fairway. These masters, of which exactly half were traditionally organized and half were team organized, were completely unconcerned with entering the fairway at the intersection and did not even feel that an immediate entrance to the fairway was important. They were first concerned with handling the immediate traffic; then, as a result of where they "ended up," they were concerned with setting a direct course for the complex and entering the fairway enroute. The major implication here is that for a deepwater port facility of somewhat comparable design, a portion of the population can be expected to approach the complex outside the safety fairway, particularly if their course is unobstructed by rigs or traffic and if entering the fairway at its entrance is perceived by them as inconvenient.

4.2.2.1 Analysis of Performance

Because there was some desire to compare performance exhibited in the dominant landfall strategy with that of the secondary strategies, performance measures and analysis identical to the dominant strategy were employed. The results, however, are not tabulated to the equivalent detail, but are presented in summary tables in Section 5 (Tables 24 and 25).

4.2.2.2 Effect of Display Enhancement and Bridge Organization on Performance

Two secondary strategies were identified as a result of the prerun discussions with subjects and as a function of how they actually transited the waterway. Subjects choosing strategy "A," shown in Figure 14, maneuvered less sharply to enter the fairway than those using the dominant strategy. Strategy "B" subjects initially maneuvered to the east to pass astern of the crossing traffic ship; then because they were well beyond the fairway intersection, set courses directly for the complex. Strategy "B" is shown in Figure 15.

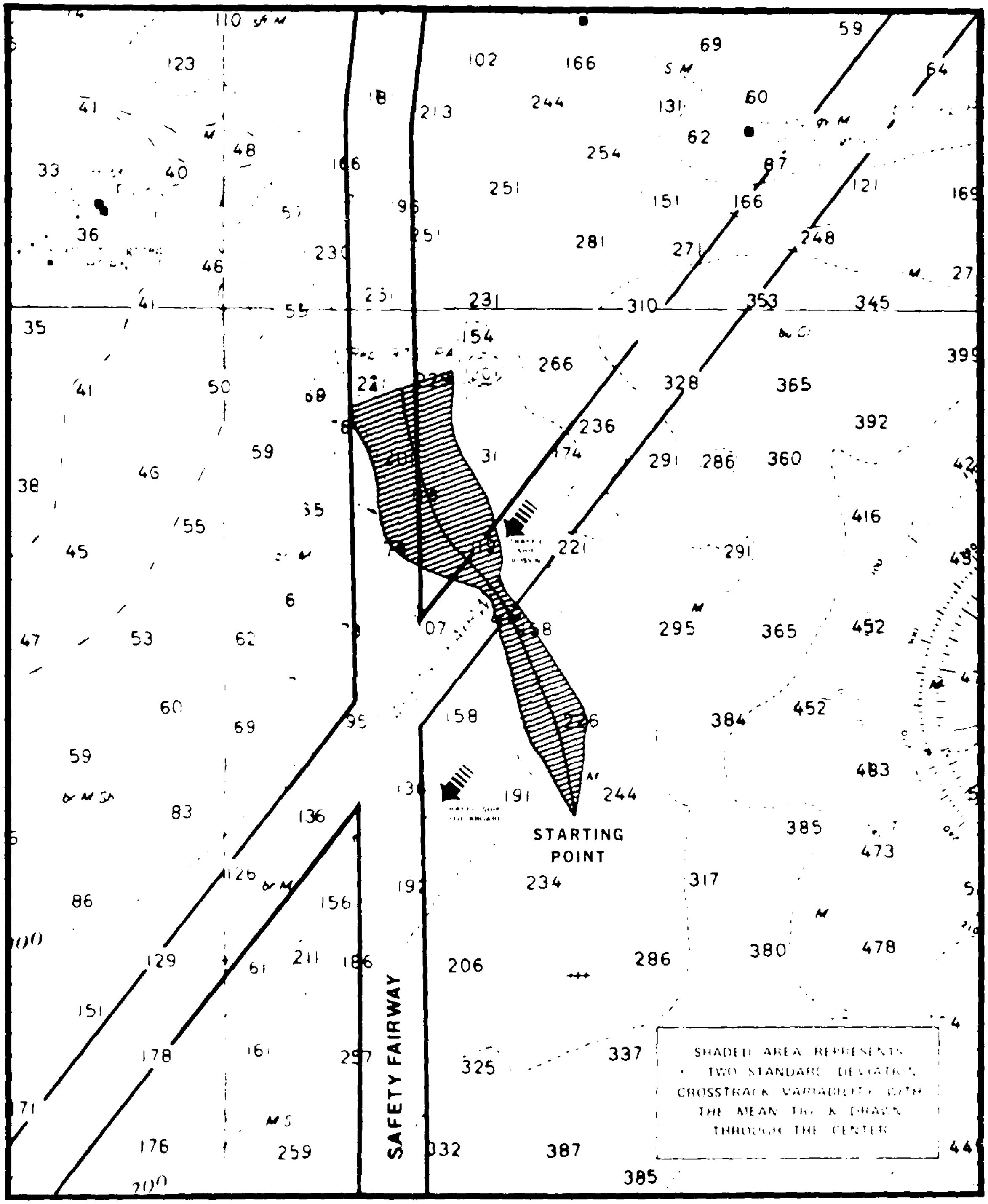

FIGURE 14. SECONDARY STRATEGY "A" OF THE LANDFALL APPROACH

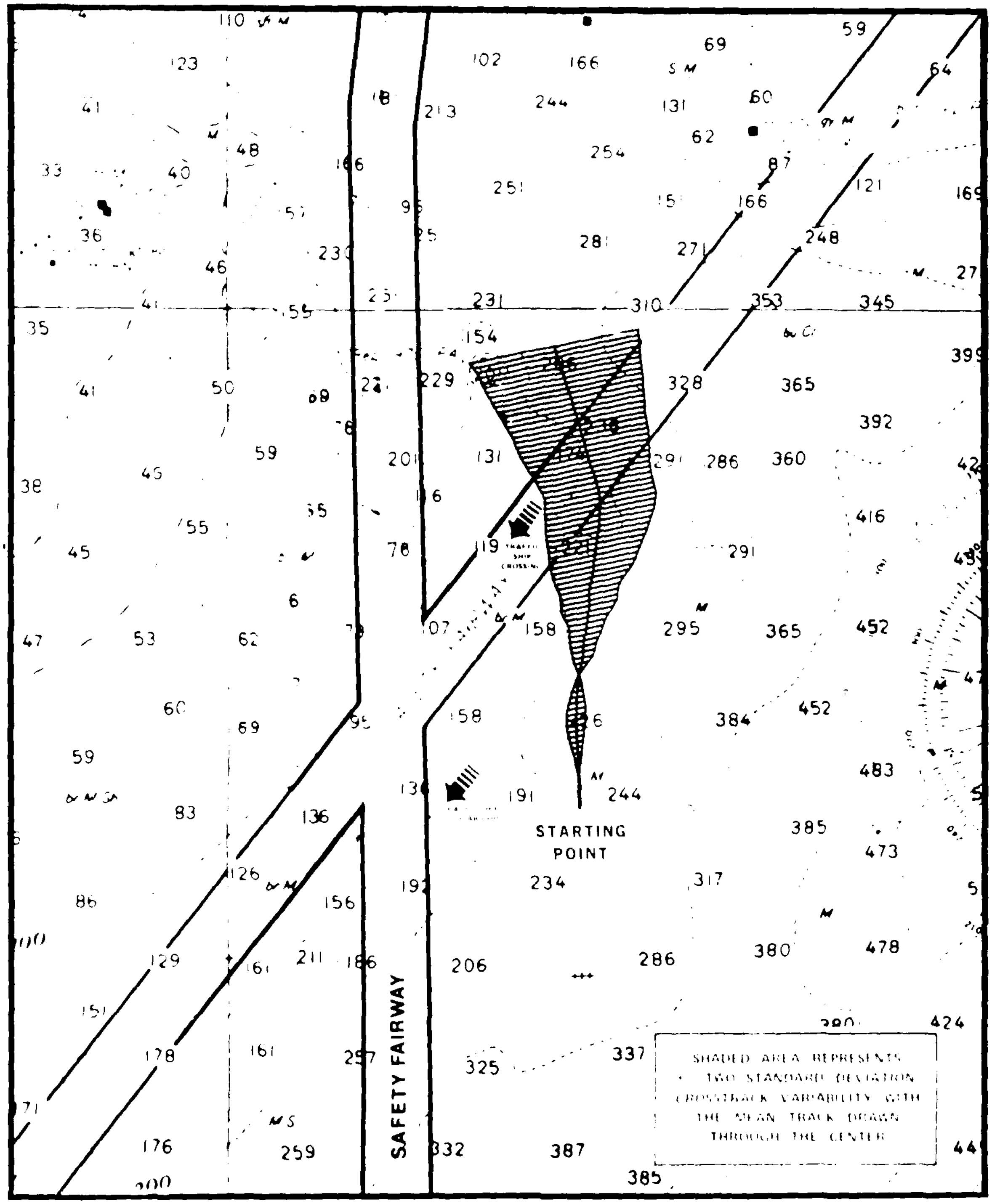

FIGURE 15. SECONDARY STRATEGY "B" OF THE LANDFALL APPROACH

Results of the analysis show that bridge organization did not have an effect on the selection of strategy, nor on performance within each strategy. In both strategies, however, subjects using the ARPA base displays tended to make larger course changes but only in the traffic avoidance maneuver. There were no other differences in crosstrack variability or between mean tracks as a function of which display enhancement was used.

Comparisons in performance for shiphandling and navigation workload showed no significant differences between variables for either of the secondary strategies. This of course could be attributed to the significantly diminished sample size. CPAs to both "close aboard" and "crossing" traffic ships, likewise, showed no significant difference as a function of variables (i.e., enhancement and organization). The conclusion is that both secondary strategies were accomplished with normal shiphandling and navigation practice and that safety as a result of CPAs to hazards was not affected. Summary Table 24 (lines 3 and 4) suggests that in secondary strategy "A" ownship passed an average of 1.79 nautical miles ahead of the "traffic ship crossing" while secondary strategy "B" ship passed an average of 2.27 nautical miles astern. In both instances, mean CPAs to the "traffic ship close aboard" were about equal.

4.2.3 Overview

Table 9 presents a brief summarization of the analysis of performance for the landfall approach scenario. An additional discussion comparing strategies and scenarios is presented in Section 5.

The analysis of run profiles in conjunction with the quantitative analysis suggests that all three strategies employed during the landfall approach were conducted safely and were characteristic of poor visibility performance. The effects of display enhancement and bridge organization as summarized in Table 9 can be expected to have similar effects on other deepwater port approaches. All conclusions which were derived from the chain of evidence could be generalized to near inshore ports or offshore ports in areas other than the Gulf of Mexico.

4.3 DERIVATION OF COASTWISE APPROACH STRATEGIES

The resultant tracks of all runs in the coastwise approach scenario are shown in Figure 16. Three unique strategies were identified in the coastwise approach, primarily as a result of the subjects' initial decision on where and how to conduct the transit. These are identified in Figure 17. The dominant strategy, which was demonstrated in 68 percent of the approaches, was to cut across the fairways, passing south of the rigs and obstructions to enter the north/south fairway near the 100 fathom line. Each of the two secondary strategies was used by 16 percent of the sample population. Secondary strategy "A" cut across the fairways, passing to the north and through the rigs. This northwest course would enable ownship to enter the north/south fairway almost at the precautionary area. Secondary strategy "B" was to enter the east/west safety fairway traveling southwest and to remain within it until its intersection with the north/south safety fairway.

As a result of the three different strategies certain rigs were encountered differently throughout the scenario. A rig which was an obstacle to the desired

TABLE 9. SUMMARY OF LANDFALL APPROACH PERFORMANCE

- The three strategies of the landfall approach which were experienced in this experiment are characteristic of the type which can be expected in a deepwater port operation.
- The frequency with which these three different strategies occurred can be considered representative of a deepwater port approach. A majority of the time, a concerted effort will be made to enter the safety fairway at its entrance. With significantly less frequency, ships diverted from the entrance as a result of traffic or other perturbation will return to the fairway as soon as possible; or will avoid any additional maneuver by entering the fairway at a small angle well beyond its entrance, providing the area is clear of rigs and traffic.
- No change in speed was indicated as a function of display enhancement or bridge organization.
- The frequency of loran fixes remained constant for all display enhancements and bridge organizations.
- CPA to traffic was unaffected as a function of which display enhancement was used. In fact, traffic avoidance was considered both exemplary and realistic for the given conditions.
- There was no significant difference in overall performance indicated solely as a function of whether radar or ARPA was used during the approach.
- There was a major tendency to direct ownship's course on a common track when using racons, thus maintaining small group crosstrack variability.
- With the addition of the navigation option to ARPA, subjects exercised significantly more maneuvering freedom as evidenced by their selection of preferred tracks and more precise positioning within the fairway
- Despite increased maneuvering with the ARPA/NAV display, subjects performed fewer radar fixes, fewer RDF fixes, and fewer DRs.
- While both organizations appeared equally intent on entering the north/south fairway near the center of the intersection, the team organization best achieved this goal. The traditional organization varied from cutting off the corner to overshooting the centerline.
- In general, the team organization performed more consistent trackkeeping with ARPA.
- There is a basic premise which must be resolved before the conclusions of this experiment can be extrapolated to deepwater port applications. The addition of racons to the scenario tended to homogenize runs, making them similar in trackkeeping. Addition of the navigation option to ARPA tended to diversify performance by accommodating individual trackkeeping preferences. The question that is raised relative to this particular waterway is whether it is more desirable to have all masters following a single track such as that promoted by the racon, or to provide masters with such precise information (i.e., ARPA/NAV) that they can maneuver at their own discretion with high confidence.

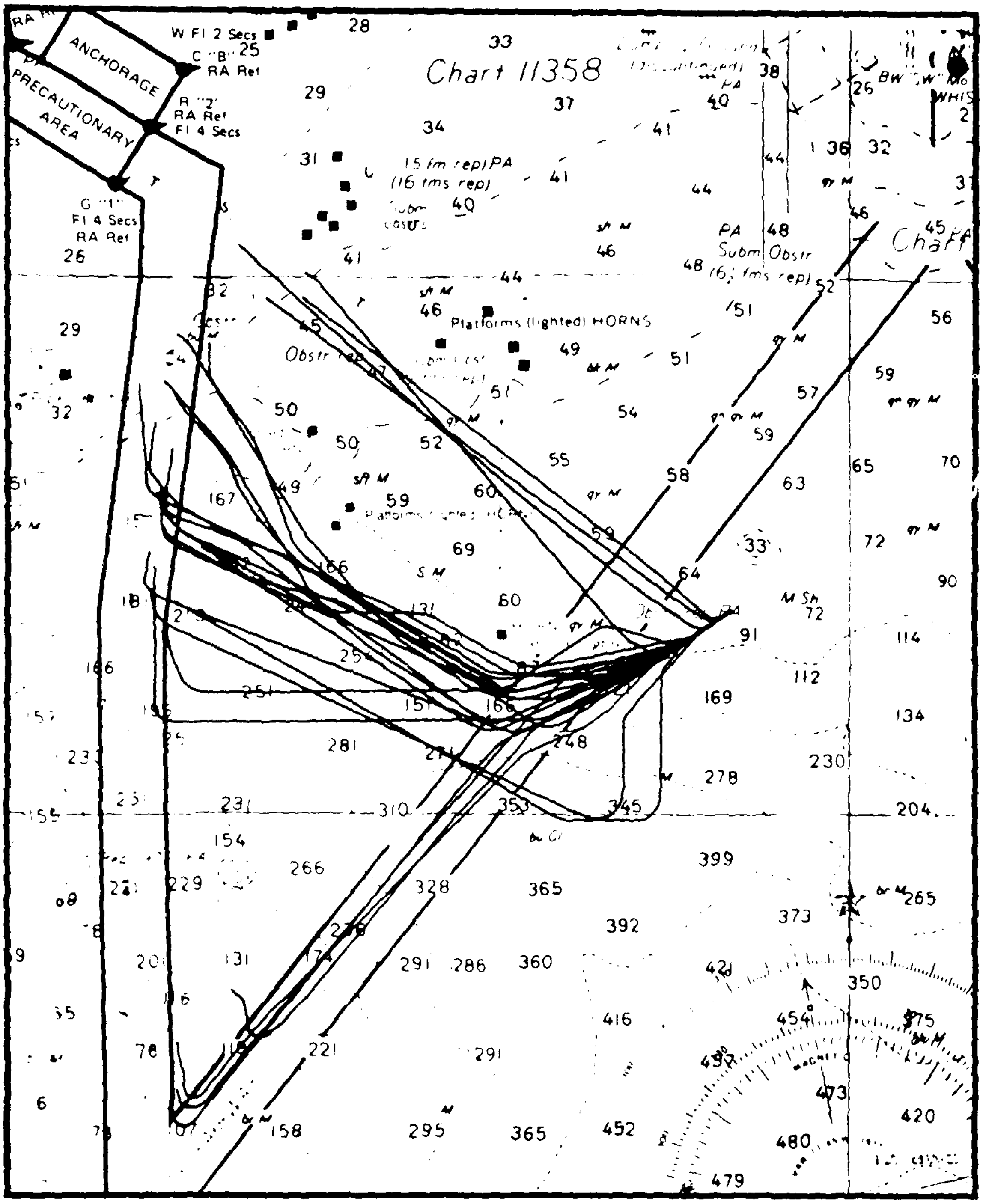

FIGURE 16. INDIVIDUAL SHIP TRACKS DURING THE COASTWISE APPROACH

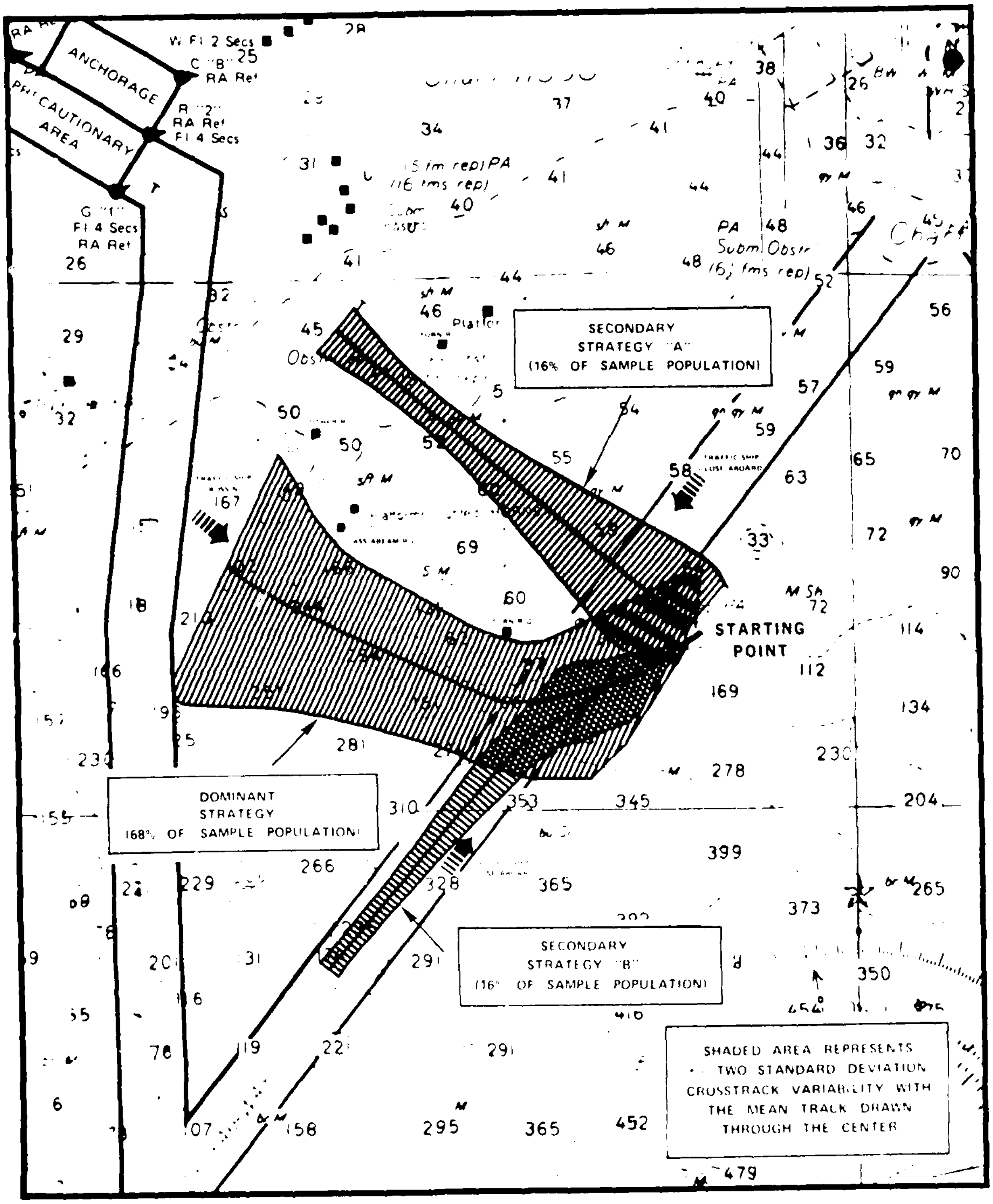

FIGURE 17. THREE STRATEGIES OF THE COASTWISE APPROACH

track and one which the subject had to maneuver around was labeled a "turn rig." A rig which was not a obstacle but which had to be passed close aboard to maintain course was labeled a "pass abeam rig." A rig which was potentially hazardous but not likely encountered was labeled "other rig." Figures 17 through 20 show the rigs for each strategy labeled according to the way they are identified in the analysis.

Again, the dominant strategy of the coastwise approach scenario can be considered characteristic of anticipated deepwater port operations and consequently is the most thoroughly examined.

4.3.1 Analysis of Dominant Strategy

Figure 18 shows the mean track and crosstrack variability of the coastwise approach dominant strategy. The group includes an equal number of runs using different display enhancements and traditional or team bridge organizations. It was anticipated that differences in crosstrack variability for this strategy would occur early in the run as a result of maneuvering to pass the "traffic ship close aboard," then maneuvering around the "turn rig" at a predetermined distance. At the same time, there should have been a desire to make ownship's actions well known to the traffic ship.

Neither the traditional nor the team bridge organization showed much difference in performance at this segment of the scenario. Greater differences in performance were shown at lower levels of interaction between organizations with a specific enhancement and at an area in the scenario southwest of the "turn rig."

4.3.1.1 Analysis of Performance

Due to the similar nature of this scenario to the landfall approach, performance measures identical to the landfall scenario were employed (see Section 4.2.1.1). However, because of the routes selected by the strategies and their close proximity to drilling rigs, the following two additional measures were added:

1. Mean CPA to each rig
2. Lowest CPA to each rig

Statistical procedures were also similar to the landfall analysis.

4.3.1.2 Effect of Display Enhancement on Performance

No statistical differences were in evidence for any of the performance measures between when the radar based displays were used and when the ARPA based displays were used. Crosstrack variability was similar for both display types; but there was an overall more northerly, close to the rigs, mean track when ARPA displays were used. The two mean track and variability plots are shown in Figures B-13 and B-14 of Appendix B. Tables 10 and 11 show no significant differences in ship control or navigation workload between display types. CPAs to the "turn rig" and "pass abeam rig" also are not statistically different. These measures shown in Table 12, however, do indicate a trend which is relevant to the research. When the ARPA based displays were used (lines 1 and 2), ownship passed 1/2 nautical mile closer to both

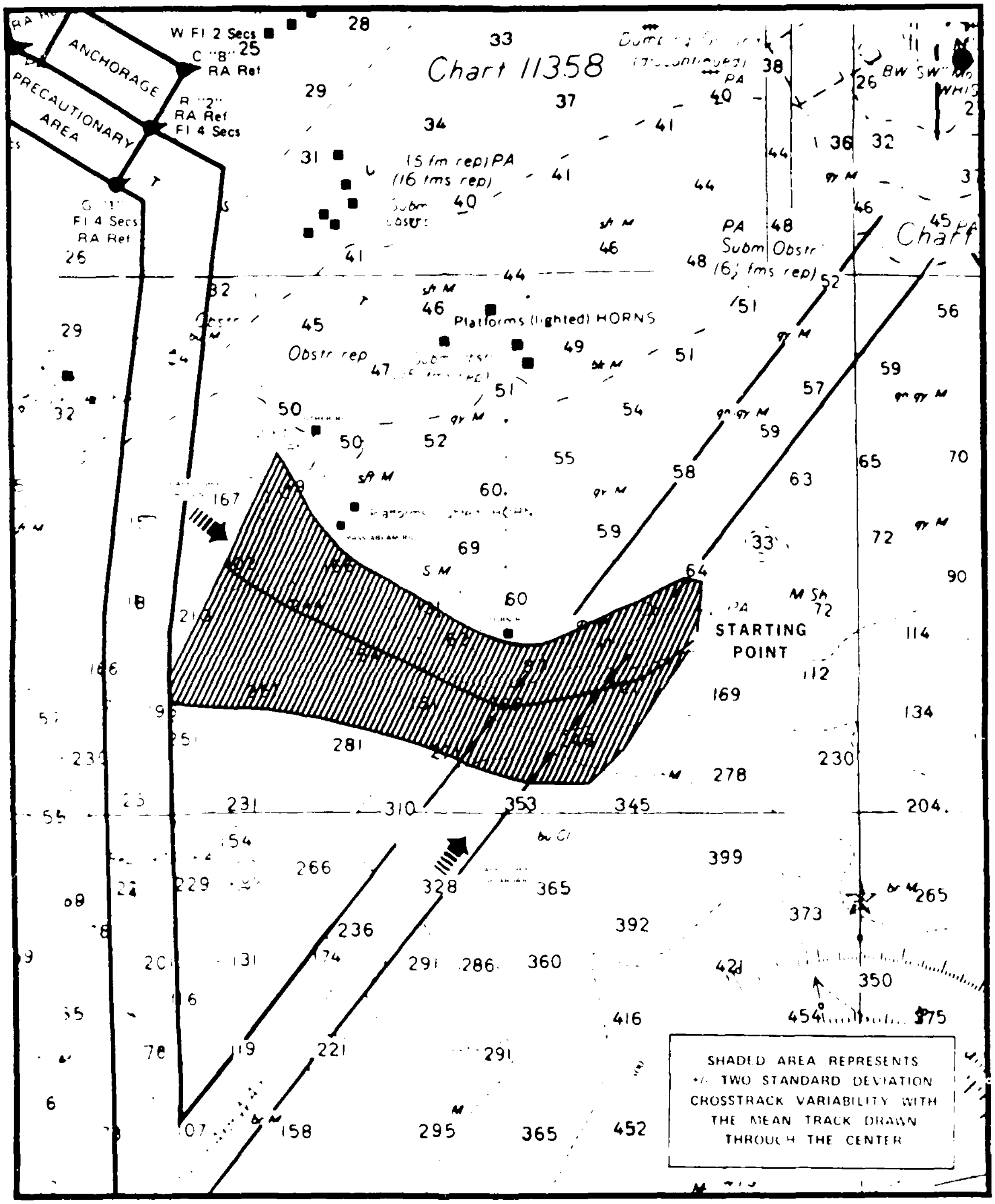

FIGURE 18. DOMINANT STRATEGY OF THE COASTWISE APPROACH

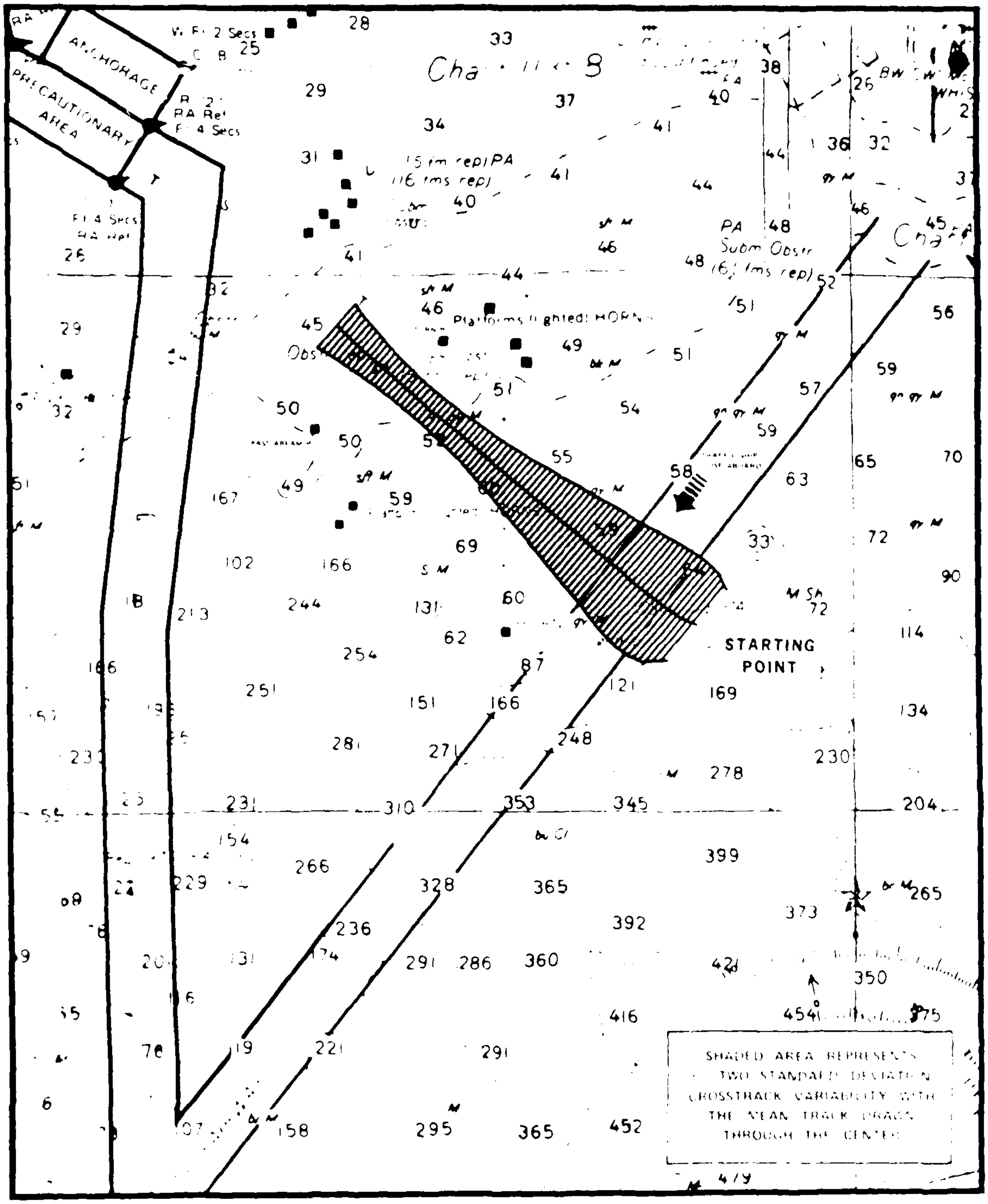

FIGURE 19. SECONDARY STRATEGY "A" OF THE COASTWISE APPROACH

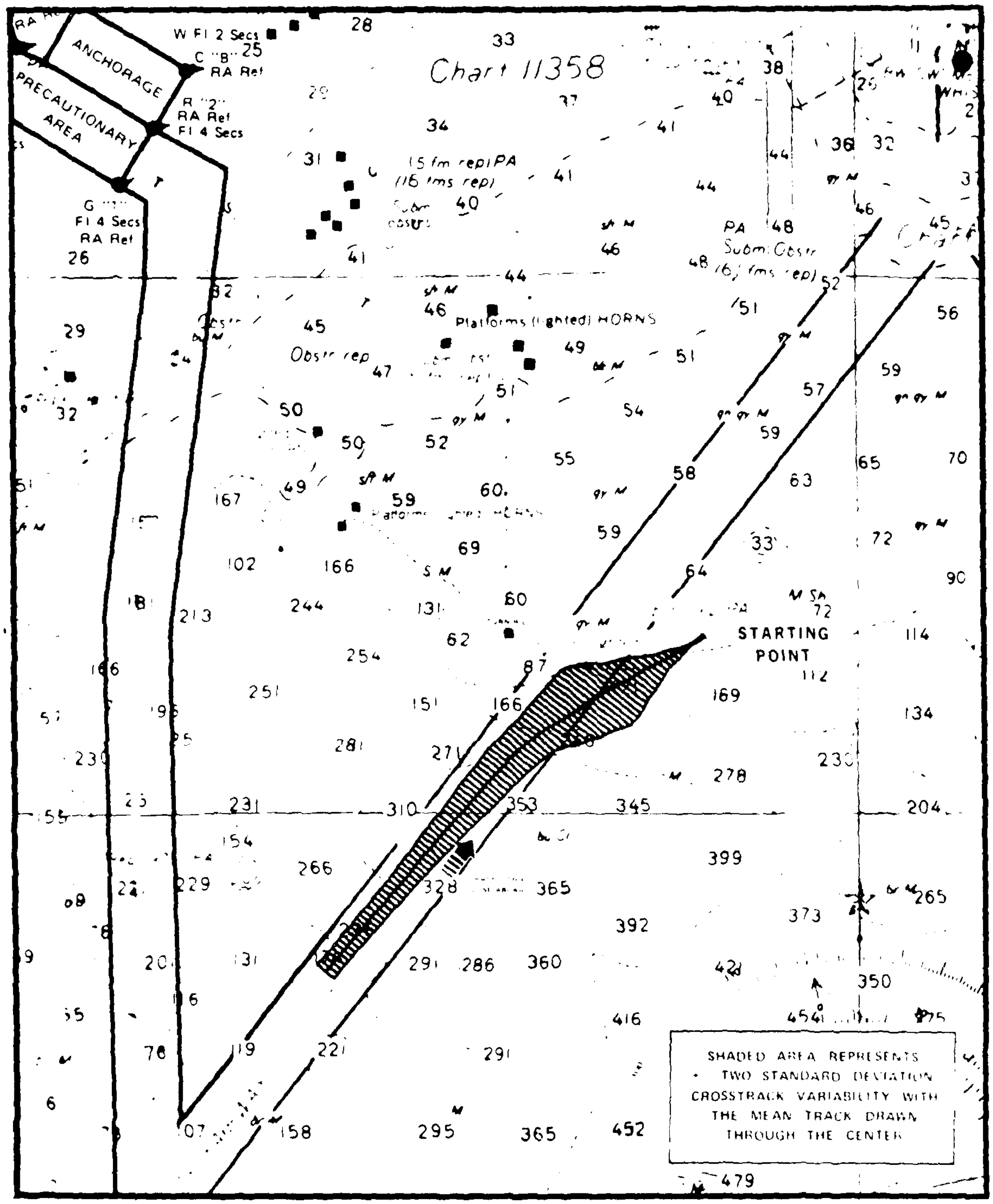

FIGURE 20. SECONDARY STRATEGY "B" OF THE COASTWISE APPROACH

TABLE 10. SHIP CONTROL AND COURSE KEEPING – COASTWISE APPROACH, DOMINANT STRATEGY

Variable	Strategy Mean: Speed (knots)	RPM	Engine Orders	Rudder Orders	Course Orders
Enhancement Effect					
1. Radar based displays	14.2	75	0.4	1.8	4.4
2. ARPA based displays	14.4	77	0.4	2.1	6.6
3. Radar	14.1	73	0.6	1.6	5.2
4. Radar/racon	14.5	77	0.2	2.0	3.5
5. ARPA	14.8	80	0.2	1.0	6.8
6. ARPA/NAV	14.0	75	0.5	3.3	6.5
Organization Effect					
7 Traditional organization	14.6	78	0.3	2.0	5.6
8. Team organization	14.0	74	0.5	1.9	5.4
9. Radar based displays - traditional organization	14.4	76	0.6	1.4	4.8
10. Radar based displays - team organization	14.0	74	0.2	2.3	4.0
11. ARPA based displays - traditional organization	14.8	80	0.0	2.8	6.5
12. ARPA based displays - team organization	14.0	75	0.7	1.5	6.8
13. Radar - traditional organization	14.8	78	0.7	1.0	6.0
14. Radar - team organization	13.0	67	0.5	2.5	4.0
15. Radar/racon - traditional organization	13.9	74	0.5	2.0	3.0
16. Radar/racon - team organization	15.0	80	0.0	2.0	4.0
17. ARPA - traditional organization	14.8	80	0.0	1.0	7.5
18. ARPA - team organization	14.8	79	0.5	1.0	6.0
19. ARPA/NAV - traditional organization	14.7	80	0.0	4.5	5.5
20. ARPA/NAV - team organization	13.2	70	1.0	2.0	7.5

NOTE: No statistical difference at $p \leq 0.10$ level of significance indicated for any value.

TABLE 11. NAVIGATION WORKLOAD – COASTWISE APPROACH, DOMINANT STRATEGY

Variable	Mean Frequency of Radar Fixes	Loran Fixes	RDF Fixes	Fathometer Fixes	DRs
Enhancement Effect					
1. Radar based displays	9.2	3.0	0.1	1.3	5.1
2. ARPA based displays	8.7	2.8	0.6	1.8	4.8
3. Radar	8.8	2.8	0.2	1.2	4.6
4. Radar/racon	9.8	3.3	0.0	1.5	5.8
5. ARPA	9.8	2.0	0.5	0.0	5.3
6. ARPA/NAV	7.8	3.5	0.7	3.5	4.3
Organization Effect					
7. Traditional organization	6.8*	2.8	0.3	1.8	3.6*
8. Team organization	12.2	3.0	0.4	1.2	6.5
9. Radar based displays - traditional organization	8.0	3.4	0.2	1.8	3.8
10. Radar based displays - team organization	10.1	2.5	0.0	0.7	6.8
11. ARPA based displays - traditional organization	5.3	2.0	0.5	1.8	3.3
12. ARPA based displays - team organization	11.4	3.5	0.7	1.8	6.2
13. Radar - traditional organization	6.3	3.3	0.3	1.0	3.3
14. Radar - team organization	12.5	2.0	0.0	1.5	6.5
15. Radar/racon - traditional organization	10.5	3.5	0.0	3.0	4.5
16. Radar/racon - team organization	9.0	3.0	0.0	0.0	7.0
17. ARPA - traditional organization	4.5	0.5	0.0	0.0	3.0
18. ARPA - team organization	15.0	3.5	1.0	0.0	7.5
19. ARPA/NAV - traditional organization	6.0	3.5	1.0	3.5	3.5
20. ARPA/NAV - team organization	9.5	3.5	0.5	3.5	5.0

* = statistically different at $p \leq 0.10$ level of significance

TABLE 12. HAZARD AVOIDANCE – COASTWISE APPROACH, DOMINANT STRATEGY

	Mean CPA to					Lowest CPA to				
	Traffic Close Aboard	Traffic Crossing	Turn Rig	Pass Abeam Rig	Other Rig	Traffic Close Aboard	Traffic Crossing	Turn Rig	Pass Abeam Rig	Other Rig
Enhancement Effect										
1. Radar based displays	1.05	3.03	2.43	2.90	5.10	0.27	0.84	1.26	1.52	2.92
2. ARPA based displays	1.73	3.04	1.97	2.62	4.79	1.01	1.82	0.95	0.99	2.13
3. Radar	1.18	3.61	2.66	3.45	5.86	0.62	1.92	1.38	1.57	4.19
4. Radar/racon	0.89*	2.32	2.15	2.22	4.16	0.27	0.84	1.26	1.52	2.13
5. ARPA	2.07	2.84	2.14	2.60	4.58	1.54	2.01	0.95	1.39	2.13
6. APRA/NAV	1.39	3.24	1.80	2.65	5.01	1.01	1.82	1.35	0.99	2.15
Organization Effect										
7. Traditional organization	1.35	3.10	1.82	2.71	4.78	0.27	0.84	0.95	1.39	2.13
8. Team organization	1.39	2.97	2.63	2.85	5.16	0.53	1.82	1.26	0.99	2.15
9. Radar based displays - traditional organization	0.95	2.78	2.19	2.60	4.61	0.27	0.84	1.38	1.57	2.92
10. Radar based displays - team organization	1.17	3.35	2.73	3.28	5.72	0.53	1.92	1.26	1.52	4.00
11. ARPA based displays - traditional organization	1.85	3.48	1.41	2.84	4.98	1.50	2.01	0.95	1.39	2.13
12. ARPA based displays - team organization	1.62	2.60	2.53	2.41	4.60	1.01	1.82	1.76	0.99	2.15
13. Radar - traditional organization	1.15	3.89	2.19	3.20	5.65	0.62	2.21	1.38	1.57	3.97
14. Radar - team organization	1.24	3.17	3.37	3.83	6.18	0.78	1.92	2.56	2.80	4.99
15. Radar/racon - traditional organization	0.66	1.13	2.21	1.71	3.05	0.27	0.84	2.02	1.59	2.92
16. Radar/racon - team organization	1.11	3.53	2.09	2.73	5.27	0.53	2.69	1.26	1.52	4.00

* = statistically different at $p < 0.10$ level of significance

TABLE 12. HAZARD AVOIDANCE – COASTWISE APPROACH, DOMINANT STRATEGY (CONTINUED)

	Mean CPA to					Lowest CPA to				
	Traffic Close Aboard	Traffic Crossing	Turn Rig	Pass Abeam Rig	Other Rig	Traffic Close Aboard	Traffic Crossing	Turn Rig	Pass Abeam Rig	Other Rig
17. ARPA - traditional organization	1.97	2.49	1.21	1.94	3.48	1.87	2.01	0.95	1.39	2.13
18. ARPA - team organization	2.18	3.20	3.06	3.27	5.68	1.54	2.69	1.76	2.12	4.60
19. ARPA/NAV - traditional organization	1.73	4.48	1.61	3.74	6.49	1.50	3.07	1.35	2.56	5.06
20. ARPA/NAV - team organization	1.05	2.01	2.00	1.56	3.53	1.01	1.82	1.90	0.99	2.15

rigs and 1/2 nautical mile further from the traffic ship close aboard. Lowest CPAs for both types of displays were about 1 nautical mile to the rigs; but when the radar base was used, only 1/4 nautical mile to the traffic ship. An examination of the run profile sheets indicated that this single low CPA represented one isolated incident which occurred not as a result of the experimental variable but from difficulty in reflection plotting the traffic ship. This problem was attributed to the reflection plotting process and could have occurred either with or without the racons. The difficulty cannot be attributed to the racon variable. It is, however, unlikely that the problem would have occurred with an ARPA based displays since they perform the plotting task automatically.

With this incident discounted, the conclusion of the radar versus ARPA comparison is that with ARPA type information available, masters may elect to transit closer to rigs in deference to other traffic. This conclusion, however, is not statistically supportable, and is further examined in the remaining analysis.

Comparison Between Radar, Radar/Racon, ARPA, and ARPA/NAV Displays. When comparing the radar with radar/racon display performance, differences are shown both for mean track and crosstrack variability (Figures A-7, B-15, and B-16). No differences are shown in CPAs to rigs (Table 12, lines 3 and 4). The significant difference in CPA to the "traffic ship close aboard" as discussed previously, is discounted as unrelated to the racon enhancement. Tables 10 and 11 show no statistical difference in shiphandling or navigation. Nevertheless, it is noteworthy that when the radar/racon was used, absolutely no RDF fixes were taken. This supports conclusions of the landfall approach that racons offer both redundant and alternative quality positioning information.

On the basis of the trackkeeping analysis and simulation observations, it is possible to conclude that subjects tended to focus their course by ranging on the racon. The racons resulted in approximately two-thirds less variance in track than the radar alone because of this focusing effect. Also the racons appeared to promote a straighter mean track with more consistency among all subjects.

In the comparison of performance between when ARPA and ARPA/NAV were used, there were no observed differences in mean tracks, but a significantly smaller variability with the ARPA/NAV display particularly at the "turn rig." See Figures A-8, B-17, and B-18. When navigating with ARPA, the masters took no Fathometer fixes; while with the ARPA/NAV, they took as many Fathometer fixes as loran fixes. The only explanation for this behavior is offered from a further review of Table 11 (lines 17, 18, 19 and 20). The table suggests that with the ARPA/NAV which synthetically displayed both rig location and fairway boundaries, masters were inclined to maintain a check of the display's accuracy as well as their own position. CPAs to traffic and rigs were unaffected (Table 12, lines 5 and 6) by the navigation option. Mean CPAs to both rigs were about 2 nautical miles; and as might be expected, the low crosstrack variability with ARPA/NAV resulted in a low variability of CPAs to the "turn rig."

In conclusion, there were no major differences in shiphandling or navigation as a function of which enhancement was used for the coastwise approach. Use of either racons or the navigation option tended to increase trackkeeping consistency among masters; but overall, all mean tracks were relatively similar, and performance differences in CPAs to the traffic ships or rigs do not warrant safety concerns.

4.3.1.3 Effect of Bridge Organization on Performance

In the coastwise approach scenario, the traditional bridge organization's performance differed from the team organization's in several ways. The traditional organization's mean track was approximately 1 nautical mile north and closer to the "turn rig" than the team organization. At the same time, the traditional organization's crosstrack variability was low while the team group's was high. To the west of the "turn rig," mean tracks were similar, but crosstrack variability for the traditional group gradually increased. This increased variability was the result of individual differences in maneuvering for the "traffic ship crossing." These results are shown in Figures A-9, B-19, and B-20. A review of Table 12 (lines 7 and 8) shows almost a 1 nautical mile greater CPA to the "turn rig" for the team organization. The analysis of navigation workload, Table 11 (lines 7 and 8) shows that the team organization took significantly more radar fixes and made more DRs than the traditional groups. This is consistent with the landfall approach scenario which also showed the team organization making more radar fixes. Again, the behavior is believed to be caused by differences in bridge procedure which result in more repetitions for the team organization. With no other significant differences shown for shiphandling (Table 10) or navigation (Table 11), it must be concluded that the major difference between bridge organizations was how they chose to maneuver around the rig and, later in the run, how they handled the crossing traffic.

The traditionally organized group consistently chose a 2-nautical mile CPA to the "turn rig" and consistently maintained this distance. On approaching the "traffic ship crossing," however, the mean CPA was 3 nautical miles but with large variability. One subject passed this ship at less than 1 nautical mile. The team organization out of preference chose different distances to pass off the "turn rig" and thus achieved a high variability. The team organization's lowest CPA to the "turn rig" was about the same as the traditional group's. However, at the "traffic ship crossing," the team organization was more consistent in its trackkeeping and CPA. It must be concluded that the team organization exercised more individual preference in maneuvering around stationary objects but more consistency when maneuvering around traffic.

4.3.1.4 Effect of Enhancement/Organization Interaction on Performance

When comparing between bridge organizations for subjects using the radar based displays, there were again those differences in mean track and crosstrack variability which were reflected in the analysis of major effects (Figures B-21 and B-22). Again, the team group's tracks show large variability at the "turn rig;" but with radar, the team group chose to keep even further from the "pass abeam rig" (Table 12, lines 9 and 10). In effect, when the team organization used radar based displays, its CPAs to all rigs and traffic averaged 1/2 nautical mile more than the traditional organization's. Aside from this, there were no shiphandling or navigation differences.

The absolute values of CPA for both organizations suggest that when radar alone was used, both teams operated more conservatively and safely in their selection of passing distances off rigs and traffic.

With the ARPA based displays, the team organization's mean CPA was larger only at the "turn rig" (Figures B-23 and B-24). Crosstrack variability was similar to that for radar, but the traditional group's CPA to the rig was 1 mile smaller. This is shown in Table 12 (lines 11 and 12) and further reflected in lines 17 through 20. Table 11 (lines 13 through 20) shows a prevailing pattern of more DRs for the team organization with all enhancements. However, when the radar/racon enhancement was used by the traditional organization, its subjects made as many radar fixes as the team organization, and more than they had for any other display enhancement. While this finding is not statistically supportable, it shows that the traditionally organized subjects did make good and consistent use of the racons when they were provided, and the racons may have prompted a more methodical adherence to the navigation process.

In conclusion, there is evidence that the traditionally organized and team organized subjects did not benefit equally from ARPA information. That this effect was actually caused by the way personnel were organized is doubted. Instead, it is suggested that the population from which the subjects were obtained and their previous experiences may have contributed to these differences. Considering their operating climate, formal training, and the sophistication of equipment to which the team organized personnel are normally exposed, it is reasonable to assume that they may have been more familiar with the operation of ARPA systems and the implementation of ARPA information.

While this is a prominent finding of the coastwise approach scenario, it is important to recognize that the introduction of racons had probably the single largest impact on performance across all organizations. The fact that racons, as in the landfall approach, tended to focus trackkeeping and thus reduce variability of tracks among subjects is in itself a factor of safety worth further investigation. Also, it is noteworthy that the racons were used extensively, perhaps more than any other enhancement, by the traditionally organized subjects. This contribution of racons is again revealed in the analysis of secondary strategies.

4.3.2 Analysis of Secondary Strategies

Two secondary strategies were identified for the coastwise approach. Secondary strategy "A" shown in Figure 19 was chosen by 16 percent of all subjects, and the only displays used were radar/racon and ARPA/NAV. This strategy required clearing the "traffic ship close aboard" (i.e., outbound from the Southwest Pass), maneuvering around rigs to the north, then passing northeast through a gap in the charted rig pattern.

Secondary strategy "B" shown in Figure 20 was also chosen by 16 percent of all subjects, and they used all display enhancements to accomplish it. The plan for this strategy was to remain within the east/west fairway to the intersection, then direct the ship up the north/south fairway to the complex. The distribution of these strategies is important to deepwater port applications because it suggests that most subjects will select the economical and convenient course as long as it is perceived as safe. The majority of subjects chose the dominant strategy to cut across the fairways by identifying a clear path and passing south of the rig structures. The subjects who chose secondary strategy "A" weighed the risk of traveling outside the rigs versus transiting through them. They determined that ample CPAs to rigs could be achieved either way, and once their course was sufficiently perturbed to the north as a result of maneuvering for the "traffic ship close aboard," they elected the northern route. The secondary strategy "B" group appeared most conservative and perhaps artificially so. Of those that did continue down the east/west fairway to the intersection, one subject suggested he would probably cut off the intersection corner anyway while another suggested that he would probably not go this way if given another opportunity. It is the conclusion of this research, although based on a small sample size, that in deepwater port applications masters will probably not hesitate to depart from or cross over fairways and transit among rigs in which CPAs in excess of their own criteria are achievable. The fact that uncharted obstructions or ship traffic may be present did not seem to alter the masters' decision.

4.3.2.1 Analysis of Performance

Because there was some desire to compare performance exhibited in the dominant coastwise strategy with that of the secondary strategies, performance measures and analysis identical to the dominant strategy were employed. The results, however, are not tabulated to the equivalent detail, but are presented in the summary tables in Section 5 (Tables 24 and 25).

4.3.2.2 Effect of Display Enhancement and Bridge Organization on Performance

Secondary strategies were chosen only by subjects from among the traditional organization. While insufficient size of the experimental sample precludes a statistical conclusion, the lack of any team organized participation in the secondary strategies suggests that organizations (and again their subsequent experience, training, equipment, etc.) could have been a factor in the selection of these strategies. If so, it implies that given the factors which comprise a team organization, it may be possible to predict how and under what conditions different masters would transit the waterway in approach to a deepwater port complex. Regretfully, this experiment can offer little for the explanation of such occurrence much less statistical proof that it even existed. It is noteworthy, however, that the masters who selected secondary strategy "A" did have extensive previous experience in Gulf of Mexico operations.

In a comparison of performance between when the radar/racon was used and when ARPA/NAV was used for secondary strategy "A," the ARPA/NAV mean track was continuously further south. Radar/racon crosstrack variability remained low due to masters' ranging on the northern most racon. ARPA/NAV, however, tended to draw the subjects' attention to objects closer and more immediate, enabling them to steer from rig to rig. The crosstrack variability for ARPA/NAV was more than four times greater than the radar/racon variability at the onset of the runs. This was due to preferential handling of the traffic ship when collision avoidance information was provided. As ownship approached the north/south safety fairway, crosstrack variability reduced as a result of splitting the distance between the "turn rig" and "pass abeam rig." See Figure 19.

A statistical comparison of performance between display enhancements within each secondary strategy was not possible due to the small sample population. Nevertheless, a number of factors were evident and are reported. In the secondary strategies the comparison of performance between when racon and ARPA/NAV were used yielded some noteworthy results.

There was no difference in CPA to any of the rigs passed abeam in secondary strategy "A." Mean CPA to the closest rig was 1.79 nautical miles for radar/racon and 1.86 nautical miles for ARPA/NAV. Lowest CPAs were 1.79 nautical miles and

1.72 nautical miles, respectively. A comparison in CPAs between all rigs passed abeam in the transit showed not only no difference as a function of display enhancement but also that all were passed at approximately the same 2 nautical mile distance. In effect, no difference in hazard avoidance was shown as a function of display enhancement for the transit north between the rigs. It is concluded that all the transits were conducted safely.

For CPAs to traffic and the rigs in secondary strategy "B," again insufficient sample size prevented statistically supportable conclusions. Nevertheless, a reporting of the trends and implications is warranted. Since in this strategy ownship remained inside the fairway, a close passing to an inbound ship as well as passing abeam the "turn rig" were required. Lowest CPAs to these potential hazards are listed below.

Enhancement	CPA to Traffic Ship (nm)	CPA to Rig (nm)
Radar	0.54	2.91
Radar/racon	0.17	3.58
ARPA	0.49	2.95
ARPA/NAV	1.11	2.12

It is evident from a review that tradeoffs in CPA between the potential hazards could well be a function of the display enhancement used. With radar, radar/racon, and ARPA, CPA to traffic is uncharacteristically low (about 1/2 mile) for a poor visibility condition; yet distance off the rig is about 3 nautical miles. With ARPA/NAV, the traffic CPA is increased to about 1 mile; and the distance to the rig, an acceptable 2 miles. In other scenarios and strategies of this experiment, CPAs of 1 and 2 miles were found to be the norm. It appears that there is evidence to suggest that ARPA/NAV does promote safer passing of potential hazards when ownship is passing between these potential hazards and when fairway boundaries, rig locations and traffic motion are well delineated.

4.3.3 Overview

An additional discussion comparing strategies and scenarios is presented in Section 5. Table 13 summarizes the findings and conclusions of the coastwise approach analysis. It is derived from the statistical analysis of measures and descriptive data obtained during the simulation such as research notes, structured observations, and responses to subject questionnaires. In general, it can be concluded that the strategies demonstrated represent an accurate accounting of the type of approaches which would be attempted at a deepwater port complex. All conclusions which were derived from the chain of evidence could be generalized to near inshore ports or offshore ports in areas other than the Gulf of Mexico.

4.4 DERIVATION OF MOORING MASTER PICKUP APPROACH STRATEGIES

The resultant tracks of all runs in the mooring master pickup approach scenario are shown in Figure 21. Three different strategies were identified primarily as a function of how quickly subjects elected to slow and their technique for slowing. The dominant strategy, which was demonstrated in 92 percent of the approaches, appeared to be the most practical in terms of shiphandling and navigation. Subjects slowed ownship by reducing rpm very soon into the run and maintained course until close to the pickup area, then altered course to position the ship for the mooring

TABLE 13. SUMMARY OF COASTWISE APPROACH PERFORMANCE

- Of the three strategies which occurred in the coastwise approach, the strategy which passed south and outside the rigs but between the safety fairways probably is most representative of what would occur under comparable conditions in a deepwater port approach.
- The two other strategies, one which passed through the rigs and one which followed the safety fairway some 30 miles "out of the way" would probably occur in deepwater port applications at a lower frequency than occurred in the simulation.
- No change in speed was indicated as a function of display enhancement or bridge organization.
- There was very little reliance upon RDF for navigating within this scenario probably because rig patterns were always within radar range.
- While there was no significant difference in overall performance indicated solely as a function of whether radar or ARPA was used. There is evidence to suggest that with radar subjects achieved lower CPAs to traffic.
- The addition of racons in the scenario significantly reduced track variability among both bridge organizations. It also promoted straighter tracks with a resultant direct and consistent route to the port complex.
- The tendency of both bridge organizations to use racons for ranging was most dramatically demonstrated in this scenario.
- No differences in overall performance between ARPA and ARPA/NAV were indicated for the coastwise approach scenario. This was probably due to the dominant strategy which transited between fairways and thus made little use of the ARPA/NAV displayed information (i.e., fairway boundaries).
- Differences were indicated between ARPA and ARPA/NAV at the "turn rig" where fairway boundaries could be displayed. These differences showed more consistency of CPAs when maneuvering around the "turn rig" with ARPA/NAV. CPAs to other rigs were relatively unaffected.
- The team organization showed greater individual preference in its selection of CPAs to rigs than the traditional group although both organizations minimum CPAs were comparable and adequate.
- The team organization showed greater consistency in its achievement of CPAs to traffic ships than the traditional organization although much of this occurred only when the team organization used ARPA.
- This consistency in performance when the team organization used ARPA also is reflected in more uniform maneuvering around the "turn rig" with other traffic in the vicinity.
- In addition to verifying that racons tend to promote a common track, the coastwise scenario further reinforced the finding that team organized subjects tended to better utilize and implement ARPA information in the conduct of their task. Whether this is due to their organization, training, or equipment experience was not resolved by the experiment.

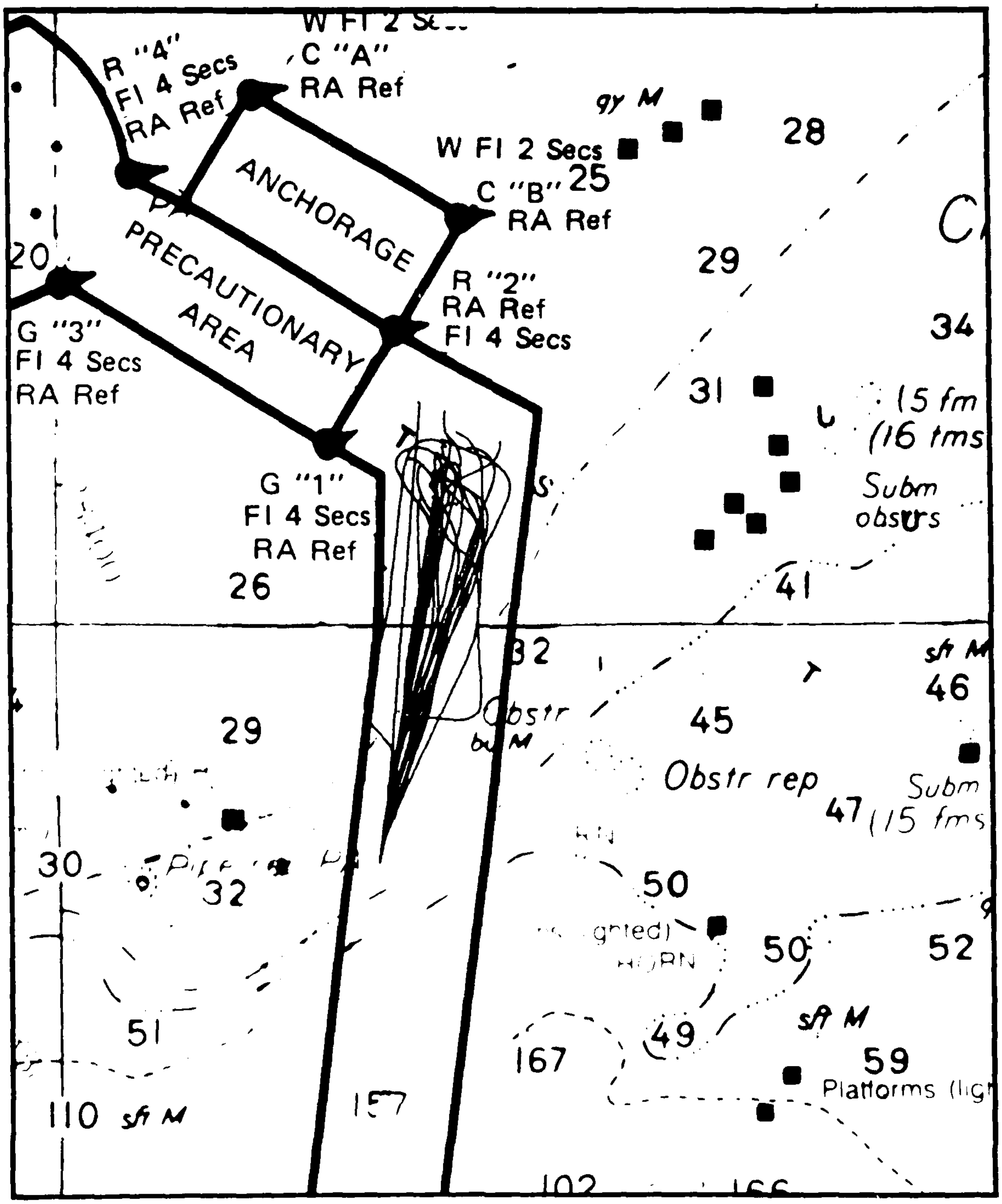

FIGURE 21. INDIVIDUAL SHIP TRACKS DURING THE MOORING MASTER PICKUP APPROACH

master's arrival. Secondary strategies "A" and "B," however (see Figure 22), involved rudder cycling and hard rudder maneuvers to slow the ship. The application of the more extreme measures exhibited in the secondary strategies is not considered necessary for slowing the ship in the required distance. The fact that 92 percent of all runs were completed satisfactorily without it provides this assurance. A review of the data shows that both secondary strategies occurred with different display enhancements, different bridge personnel organizations, and at a different time in the simulation schedule. For one subject, it was his first run through this scenario; for the other subject, it was his second run. For these reasons, it was decided to analyze these two strategies separately.

Again, the dominant strategy of the mooring master pickup approach can be considered characteristic of anticipated deepwater port performance and consequently is the most thoroughly examined. While the secondary strategies were of significantly lesser frequency, their actual occurrence suggests that users probably would not hesitate departing from the safety fairway in order to accomplish shiphandling goals (such as slowing) which they consider more important.

4.4.1 Analysis of Dominant Strategy

Figure 23 shows the mean track and crosstrack variability of the dominant mooring master pickup strategy. The group includes approximately twice as many traditional organized subjects as team organized subjects. There are an equal number of runs in this scenario for each display enhancement. The strategy consisted of subjects heading toward the precautionary zone without major course changes until they arrived at the pickup point. Maneuvers at and beyond the pickup point were based solely upon individual preference (see Figure 21) and, as a result, represented substrategies. Subject performance within these substrategies was not quantified but is analyzed descriptively in Section 4.4.4.

The analysis plot in Figure 23 shows small track variability early in the run which gradually increased as individual preferences for the pickup developed. Some subjects elected to remain to the right, others to the left of the fairway; still others transited in the center. This difference in behavior is not attributed to display enhancement although bridge organization with its consequent experience, training, and procedures may have had an effect. This was investigated.

4.4.1.1 Analysis of Performance

Performance measures and the application of statistics to the dominant strategy of the mooring master pickup approach are the same as items 1 through 5 for the landfall approach scenario (see Section 4.2.1.1). The absence of rigs and traffic close aboard made CPA an impractical measure of performance. CPAs to the mooring master pickup point were never achieved due to the design of the scenario (i.e., according to the script, the mooring master never arrived).

Descriptive measures of performance included:

1. Decision of subject at first delay
2. Maneuver technique following first delay
3. Ability to achieve the maneuver goal following first delay

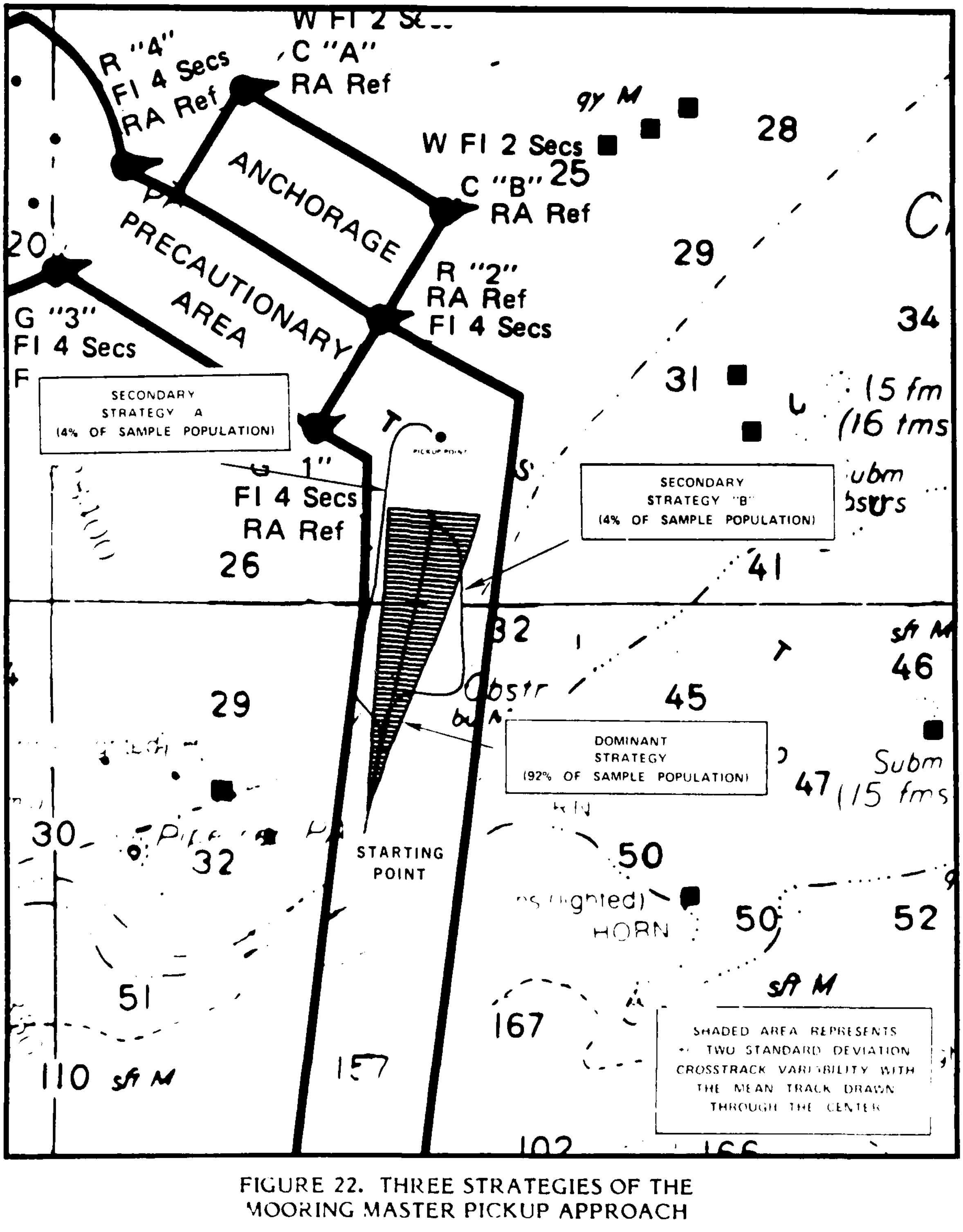

FIGURE 22. THREE STRATEGIES OF THE MOORING MASTER PICKUP APPROACH

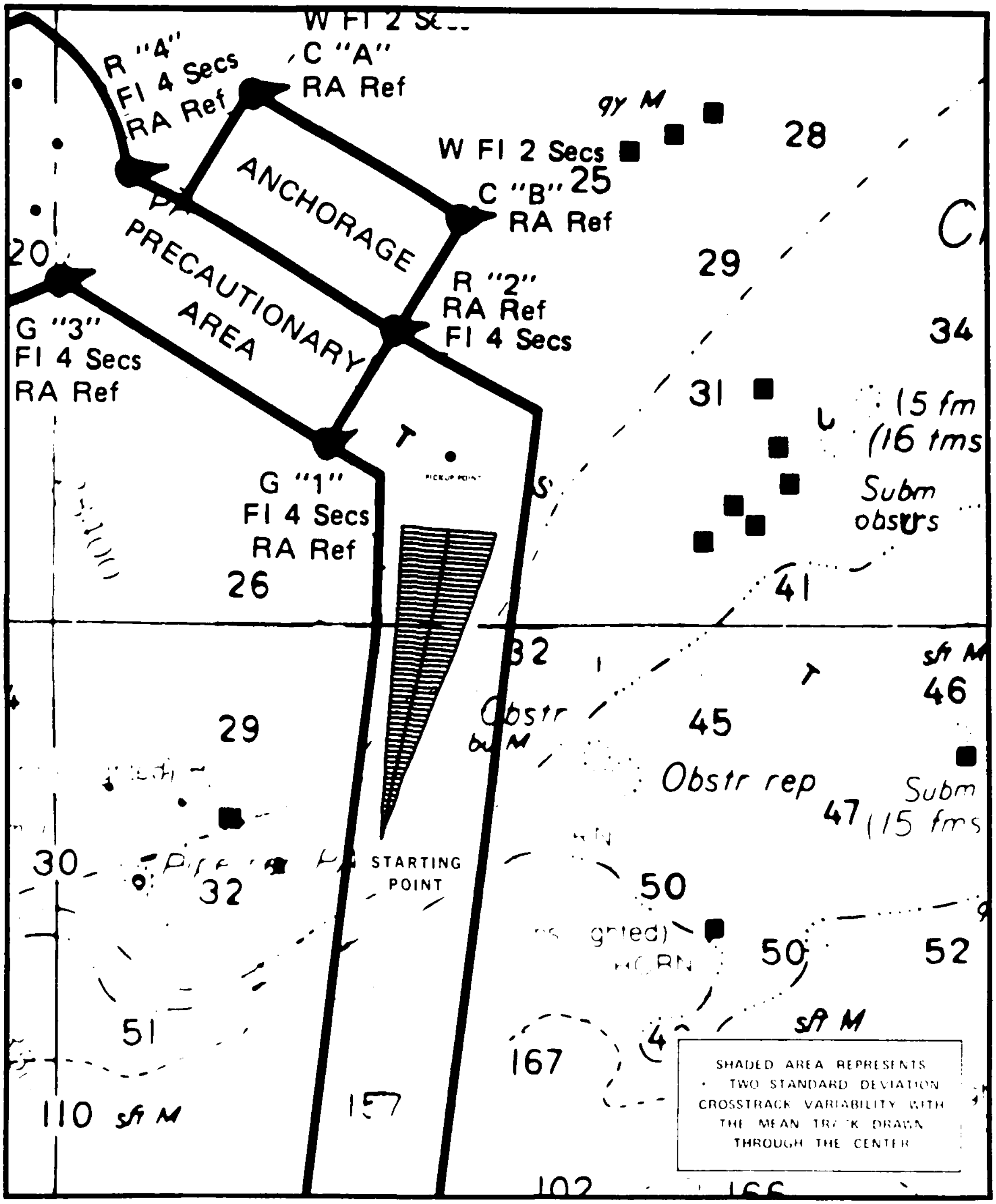

FIGURE 23. DOMINANT STRATEGY OF THE MOORING MASTER PICKUP APPROACH

4. Decision of subject at second delay
5. Maneuver technique following second delay
6. Ability to achieve the maneuver goal following second delay

4.4.1.2 Effect of Display Enhancement on Performance

A review of Tables 14 and 15 (lines 1 and 2) and Figures B-25 and B-26 in Appendix B reveals few differences in overall performance between when the radar based displays were used during the approach and when ARPA based displays were used. The radar based displays resulted in some smaller crosstrack variability early in the run, but this is believed to have resulted mostly from the effect of the racon. There is no indication of significant differences in maneuvering as a result of the major enhancements. A review of observations on how subjects slowed along with the actual measurements of slowing (i.e., rpm and engine orders) suggests that all subjects slowed quite comparably.

Comparison Between Radar, Radar/Racon, ARPA, and ARPA/NAV Displays. In the comparison of performance between when radar alone was used and when radar/racon was used, there is a highly significant difference in crosstrack variability. This is shown graphically in Figures B-27 and B-28, and statistically in Figure A-10. While shiphandling and navigation workload did not differ, the results again show the common track or focusing effect which racons seem to produce.

From observation, the northern racon apparently was used for radar parallel indexing, a piloting technique which resulted in more direct and consistent tracks straight to the pickup point. The large crosstrack variability with radar was caused by two-thirds of the subjects heading toward the right side of the fairway and ranging on the middle buoy, and one-third altering course left toward the port buoy marking the precautionary area. The radar enhancement thus produced a mean track 1/2 mile further east, to the right side of the fairway. As a result, substrategies were indicated for the radar display but not the radar/racon display. This in itself suggests that when racons are available, there may be more enticement to use them for parallel indexing with the radar display. Observer data show this technique to be used almost exclusively. Tables 14 and 15 (lines 3 and 4) suggest few differences other than tracks made good. Overall reduction of speed was comparable as were the frequency of navigation fixes, engine orders, rudder orders, and course orders.

The performance comparison between when ARPA and ARPA/NAV displays were used produced significant differences. Subjects appeared less constrained with ARPA/NAV and tended to exercise more options with the additional navigation information (i.e., fairway boundary delineations and buoy designations). The ARPA/NAV mean track was considerably further to the right of the fairway (Figures B-29 and B-30) with significantly greater crosstrack variability midway through the approach (Figure A-11). A further comparison using Figures B-27 and B-28 of Appendix B reveals that:

- Both ARPA and radar/racon mean tracks are comparable, although ARPA has a significantly higher crosstrack variability.
- Both ARPA/NAV and radar mean tracks are comparable, and both have moderate crosstrack variability.

TABLE 14. SHIP CONTROL AND COURSE KEEPING – MOORING MASTER PICKUP APPROACH, DOMINANT STRATEGY

Variable	Strategy Mean: Speed (knots)	RPM	Engine Orders	Rudder Orders	Course Orders
Enhancement Effect					
1. Radar based displays	7.5	17	3.6	2.2	1.8
2. ARPA base displays	8.1	25	3.4	1.1	2.6
3. Radar	7.5	20	4.0	2.3	2.3
4. Radar/racon	7 4	14	3.2	2.0	1.2
5. ARPA	7.6	19	3.7	0.2	2.5
6. ARPA/NAV	8.6	31	3.2	2.0	2.7
Organization Effect					
7 Traditional organization	8.0	23	3.7	1.8	1.8
8. Team organization	7.3	17	3.0	1.1	3.1
9. Radar based displays - traditional organization	7.5	17	3.9	2.4	1.2
10. Radar based displays - team organization	7.4	16	3.0	1.8	2.8
11. ARPA based displays - traditional organization	8.4	28	3.6	1.3	2.2
12. ARPA based displays - team organization	7.3	17	3.0	0.3	3.7
13. Radar - traditional organization	7.3	17	4.0	3.5	2.0
14. Radar - team organization	8.2	36	4.0	0.0	3.0
15. Radar/racon - traditional organization	7.8	18	3.7	1.2	0.5
16. Radar/racon - team organization	6.6	6	2.0	3.5	2.5
17. ARPA - traditional organization	7.8	20	4.3	0.0	2.0
18. ARPA - team organization	7.3	16	2.5	0.5	3.5
19. ARPA/NAV - traditional organization	8.9	34	3.0	2.4	2.4
20. ARPA/NAV - team organization	7.2	21	4.0	0.0	4.0

NOTE: No statistical difference at $p \leq 0.10$ level of significance indicated for any value.

TABLE 15. NAVIGATION WORKLOAD –
MOORING MASTER PICKUP APPROACH, DOMINANT STRATEGY

Variable	Mean Frequency of Radar Fixes	Loran Fixes	RDF Fixes	Fathometer Fixes	DRs
Enhancement Effect					
1. Radar based displays	7.2	0.9	0.1	0.3	2.6
2. ARPA based displays	6.2	0.7	0.0	0.9	1.6
3. Radar	6.3	0.5	0.0	0.2	2.5
4. Radar/racon	8.0	1.3	0.2	0.5	2.7
5. ARPA	7.0	0.7	0.0	1.7	2.8
6. ARPA/NAV	5.5	0.7	0.0	0.2	0.3
Organization Effect					
7. Traditional organization	5.8	0.8	0.1	0.2	1.8
8. Team organization	8.9	0.9	0.0	1.6	2.7
9. Radar based displays - traditional organization	6.8	0.7	0.1	0.2	2.6
10. Radar based displays - team organization	8.0	1.2	0.0	0.5	2.5
11. ARPA based displays - traditional organization	5.0	0.8	0.0	0.2	1.1
12. ARPA based displays - team organization	10.0	0.3	0.0	3.0	3.0
13. Radar - traditional organization	6.8	0.5	0.0	0.2	3.0
14. Radar - team organization	5.5	0.5	0.0	0.0	1.5
15. Radar/racon - traditional organization	6.8	1.0	0.2	0.2	2.3
16. Radar/racon - team organization	10.5	2.0	0.0	1.0	3.5
17. ARPA - traditional organization	6.2	0.7	0.0	0.2	2.5
18. ARPA - team organization	8.5	0.5	0.0	4.5	3.5
19. ARPA/NAV - traditional organization	4.0	0.8	0.0	0.2	0.0
20. ARPA/NAV - team organization	13.0	0.0	0.0	0.0	2.0

NOTE: No statistical difference at $p \leq 0.10$ level of significance indicated for any value.

A check of ship control and navigation workload measures (Tables 14 and 15) shows overall few loran, RDF and Fathometer fixes regardless of which enhancement was used. Although not statistically significant, there were considerably fewer DRs when ARPA/NAV was used which would be expected.

In general, conclusions from the mooring master pickup approach in terms of display enhancement, must be drawn from the trackkeeping performance. This can be summarized as follows:

1. With the radar display, traditional pilotage prevailed. There was a tendency by some subjects to keep to the center of the fairway; however, most subjects gradually moved to the right to avoid potential traffic and because they considered this a more "comfortable" (sic) position to receive the mooring master.

2. When racons were available, all subjects headed directly toward the pilot pickup point in the center of the fairway.

3. With the ARPA display, most subjects kept to the center of the fairway confident with their added ARPA information that they could avoid any traffic encounter. Some subjects gradually moved to the right similar to the radar enhancement.

4. When the navigation option was added to ARPA (i.e., ARPA/NAV), some subjects immediately moved to the right, some remained left, and others continued up the center. Apparently the ARPA/NAV display instilled the greatest confidence in the subjects, allowing them to maneuver and position themselves in the fairway exactly where they intended

4.4.1.3 Effect of Bridge Organization on Performance

When comparing traditional organization with team organization in the mooring master pickup approach, no differences in performance were indicated. Figures B-31 and B-32 show almost identical trackkeeping performance while Tables 14 and 15 show no significant shiphandling or navigation workload differences.

4.4.1.4 Effect of Enhancement/Organization Interaction on Performance

As might be expected by the previous discussion, little difference in performance was indicated between bridge organizations as a function of whether radar based or ARPA based displays were used. Instead, the interaction analysis concentrated on individual enhancements and the effect bridge organization might have on them.

The [illegible] of track plots for the traditional and team organizations when they [illegible] s a small difference in mean tracks but significant difference in [illegible] ability. The traditionally organized group had more than double the [illegible] at the mooring master pickup point, with their mean track [illegible] of the fairway. All team organized subjects using radar kept [illegible] organizations demonstrated comparable speed reduction, [illegible] orders.

[illegible] showed no difference between [illegible] variability. This is one of the more useful findings of the mooring master pickup scenario since it indicates that when racons are used, trackkeeping performance may be highly predictable regardless of bridge personnel experience, training, or organization.

When comparing ARPA and ARPA/NAV trackkeeping performance between bridge organizations, mean tracks and crosstrack variability were similar, and this variability gradually increased for both organizations up to the mooring master pickup point. See Figures A-12, B-31 and B-32. Also, there were no significant differences in shiphandling or navigation tasks between the bridge organizations. It is concluded that whatever differences did occur between ARPA and ARPA/NAV, they were not the result of bridge personnel experience, training or organization.

It is further concluded that the dominant strategy was conducted safely by all subjects and that differences in the approach to a deepwater port mooring master pickup will be manifest in the approach route and not the means by which it is achieved. As a result, the safety and appropriateness of a mooring master pickup could possibly be enhanced by specifying the approach route; and this, as the experiment has shown, could be achieved through the use of prudently located racons.

4.4.2 Analysis of Secondary Strategies

Only 8 percent of the sample population chose a strategy different from the dominant strategy in the mooring master pickup approach scenario. These secondary strategies, shown in Figure 22, differed from the dominant strategy both in track and rudder utilization with a resultant significant effect on ship speed. While the two strategies were conducted differently and are so analyzed, the result common to both but different from the dominant strategy was an initial major reduction in speed with a subsequent very slow approach toward the mooring master pickup point. The requirement to remain within the safety fairway was essentially deferred.

4.4.2.1 Analysis of Performance

To compare performance exhibited in the dominant mooring master pickup approach strategy with that of the secondary strategies, performance measures and analysis identical to the dominant strategy were employed. Small sample size of the secondary strategies precluded a statistical comparison of many measures; nevertheless, data are presented in Section 5 (Table 25).

4.4.2.2 Effect of Display Enhancement and Bridge Organization on Performance

In secondary strategy "A," a traditionally organized bridge crew using the radar display moved well to the left of the fairway and used the platform racon and buoy number one for ranging. The crew performed few radar fixes. They initially reduced speed quickly by reducing rpm and rudder cycling, then increased rpm for short durations to maintain steerageway. Overall the approach to the pickup point was very slow. This strategy was best characterized by the crew's intention to slow the ship quickly and early instead of gradually. This is shown in the summary data presented in Section 5 (Table 25, line 12) by slowest mean speed, lowest mean rpm, most engine orders, and most rudder orders.

In secondary strategy "B," a team organization using the ARPA/NAV display immediately ordered hard right rudder to slow the ship, made a lengthy turn outside the fairway, then reentered it further north but at a much reduced speed. The subjects stated that they would much prefer to have the mooring master wait for them than have to station keep or circle at the pickup point. The summary data in Section 5 (Table 25, line 13) show that this strategy was conducted at an average comparable speed with the dominant strategy but with considerable manipulation of the throttle. In fact, while the dominant strategy gradually reduced speed, secondary strategy "B" slowed early in the initial maneuver, then proceeded at a constant slow speed to the pickup point.

In summary, the conduct of both secondary strategies appears to have been a very well planned and executed tactic for approach to the mooring master pickup. Whether the initial maneuver to slow was really warranted or even necessary can only be judged by the outcome. If it is desirable to approach at a slower speed, in the real world, the master would have ample opportunity to do so prior to where he started the simulation. In this case, such a maneuver might not be necessary.

4.4.3 Overview

The conclusion of the analysis and its application to deepwater ports operations suggests that the approach as demonstrated in the dominant strategy is valid and safe. It shows the feasibility of a gradual reduction in speed. The approaches demonstrated in the secondary strategies would probably never occur because individuals desiring a slower transit would have already slowed prior to the location where the simulation started. In any event, the satisfactory conduct of both secondary strategies does suggest that emergency and/or rapid slowing is possible at the mooring master pickup point regardless of display enhancement or bridge organization.

Table 16 presents a brief summarization of the analysis of performance for the mooring master pickup approach scenario. An additional discussion of strategies and scenarios is presented in Section 5. Of the three strategies experienced in the experiment, only the dominant strategy is expected to normally occur at the approach to a deepwater port complex. Further, conclusions suggest that the approaches, as they were simulated, were conducted with comparable safety. These conclusions which were derived from the chain of evidence could be generalized to near inshore ports or offshore ports in areas other than the Gulf of Mexico.

4.4.4 Delay Consequences at the Mooring Master Pickup Point

A descriptive analysis is provided which compares the effects of display enhancements and bridge organizations for subject actions after they were told that the mooring master's arrival would be delayed. Two delays were analyzed separately. In the first, subjects were informed the master would be delayed about 30 minutes. In the second, they were informed he would be delayed several hours. Following the first delay notice, subjects were permitted to achieve their decision goal. After their second delay notice, subjects were evaluated on how well they began to achieve their decision goal.

All results were analyzed by (1) categorizing each decision such as stopping, circling, returning to sea; (2) identifying the maneuver which was required such as reducing rpm, rudder cycling, hard turning; and (3) actual achievement of the goal.

TABLE 16. SUMMARY OF MOORING MASTER PICKUP APPROACH PERFORMANCE

- Of the three strategies experienced in the mooring master pickup approach, only the normal straight ahead while slowing technique would be expected to occur for the majority of ships entering a deepwater port.
- The extreme measures for slowing such as rudder cycling and hard turns which occurred during the secondary strategies of the approach, are expected to occur infrequently in the real world.
- Strategies for the approach to a deepwater port mooring master pickup will vary in rate of slowing and/or position within the fairway when approaching the pickup point. All will be conducted characteristic of normal pilotage, regardless of display enhancement or bridge organization.
- Approach tracks were the main differences in performance shown for the dominant strategy to pick up the mooring master. Shiphandling, rate of slowing, and navigation workload were for the most part unaffected.
- The existence of the two alternatives to slowing straight ahead suggests that masters would not hesitate to leave the safety fairway in order to adjust their speed.
- Performance differences which did occur as a function of display enhancement or bridge organization occurred close to the mooring master pickup area where actual maneuvering to receive the mooring master was necessary. Initial coursekeeping and slowing tactics were not affected.
- *There was no significant difference in overall performance* indicated solely as a function of whether radar based or ARPA based displays were used during the approach.
- There was a highly significant reduction in trackkeeping variability and a straighter, more direct mean track to the pickup point as a result of introducing racons to the scenario. This is believed to have occurred as a result of radar parallel indexing on the racons.
- Runs with ARPA and ARPA/NAV showed a significant increase in individual options for the mooring master approach and pickup. Individual preferences were exercised for positioning ownship in the center of the fairway with ARPA and to the right, left, and center with ARPA/NAV. The delineated fairway boundaries and buoys evidently provided an additional dimension of navigation confidence in the overall pilotage.
- Major differences were shown in subject responses to delays in the arrival of the mooring master. While these responses were diverse, results of the analysis suggest (1) that all were characteristic of normal shiphandling procedures in a comparable situation, (2) that they were accomplished safely and could have been fulfilled given adequate time, and (3) that they occurred as a function of individual preference and not display enhancement or bridge personnel organization.
- The highly diverse maneuvers which were exhibited at the mooring master pickup point when the mooring master was delayed suggests a major uncertainty among masters as to the best course of action in such instances.
- The diverse and consequently unpredictable responses of masters to the mooring master delay were the result of difficulties in handling a loaded VLCC at low

TABLE 16. SUMMARY OF MOORING MASTER PICKUP APPROACH PERFORMANCE (CONTINUED)

speeds with the given environmental conditions while at the same time maneuvering through the safety fairway dogleg. • Masters are characteristically suspicious that once the mooring master is delayed it is likely the delay will be extended. As a result, they plan their contingency maneuver to accommodate an extended delay. • The ability to satisfactorily convert all initial contingency maneuvers to extended delay maneuvers was achieved prior to terminating each simulation.

It is obvious from the following description of subject responses that no differences in this performance were revealed which could be attributed solely to display enhancement or to bridge organization. The results of the analysis suggest that any of the described tactics could be employed at a deepwater port in the event the mooring master is delayed. Further the tactics could be accomplished with a minimum of risk as tested in the simulation and might be experienced in real world settings with the frequency of occurrence revealed by the simulation. Variations in subject's actions appear to be a function of individual preference and/or experience and are not attributed to display enhancement or bridge organization.

Radar Display. When the radar alone was being used during the first delay notification, subjects either circled in the fairway, turned the ship 180 degrees and drifted, stopped the ship by various engine orders and let it sit, found a shallow spot to anchor the ship, returned to sea, or maneuvered east out of the fairway slowly turning the ship around to meet the mooring master at the new time. There was no identifiable difference in these responses as a function of bridge organization.

When the second delay was issued, subjects maintained their original decision and continued to carry out their plan.

Radar/Racon Display. When racons were added to the scenario, responses varied but with no established pattern to suggest that they were caused by bridge organization. Subjects either swung to the right and sat, anchored, steered well out of the fairway in consideration of traffic, circled to the left, turned 180 degrees and steamed down the channel at slow speed, left the deepwater port area until visibility cleared, turned to the starboard with very little way on, or after notifying the deepwater port facility, maneuvered a slow racetrack turn in the safety fairway.

Again, the second delay notification prompted a continuation of the planned procedure but with a more serious consideration toward anchoring just outside the channel. This is evidence that the existence of racons instilled an added degree of confidence contributing to the decision to anchor outside the fairway.

ARPA Display. When the subjects using ARPA were informed the mooring master would initially be delayed, they either stopped engines and drifted, altered course to leave the fairway and anchor, left the fairway to circle, turned the ship 180 degrees and steamed down the fairway, or drifted in the fairway where there would be no traffic. There was no difference indicated as a function of bridge organization.

Responses to the second delay produced no major changes in plans. With this display, subjects appeared more content to drift in the fairway knowing they would have ample detection of approaching traffic.

ARPA/NAV Display. When subjects using the ARPA/NAV were informed the mooring master would be delayed, they either anchored on the spot if there was no traffic, stopped the ship southeast of th signated anchorage, left the fairway and circled the rigs to the northeast, steamed inshore to the 16 to 19 fathoms area and anchored, let the ship circle 360 degrees, or turned the ship to the right then slowed the engines to kill the way. One subject said in the event of a long delay, he would enter the anchorage whether allowed to or not. Another subject said if there were more traffic, he would leave the fairway and drop anchor until the visibility cleared. Although there were no differences noted as a function of bridge organization, the numerous and potentially complex options proposed suggests that with ARPA/NAV subjects may have been more confident both of their actual position and of their ability to maneuver within the area.

Notification of the second delay did not appreciably change original plans or maneuvers already underway.

All Enhancements, All Organizations. An additional finding relevant to any port operation is that once masters were notified of a mooring master delay, regardless of the estimated time of the delay, they tended to choose a "holding maneuver" which could easily and safely be extended in time or which could be converted for an indefinite delay. In the simulation, when the delay was extended, it provided the masters an excellent opportunity to test the appropriateness of their initial decision. In general, all were pleased.

4.5 DERIVATION OF DEGRADED DEAD RECKONING APPROACH

Unlike the other scenarios in which strategies were revealed just prior to the simulation and as a function of how well the strategy goal was achieved, the strategies of the degraded DR approach were categorized by the initial response of the subject as soon as he was sure of his actual position. These results are shown in Figure 24.

Of the three strategies identified, the dominant strategy consisted of all runs which, once the subject was sure of his position, turned toward the LOOP complex to enter the north/south fairway well north of the intersection. A different strategy turned approximately 135 degrees back to the intersection. This was considered an unlikely but possible maneuver and was labeled secondary strategy "A" (see Figure 25). In the third strategy (secondary startegy "B"), as soon as the subject doubted his position he turned southwest to travel down the east/west fairway. When he was sure that the DR was in error, he continued on a reciprocal RDF bearing while using a "line of soundings" to determine his position. Upon determining his position he turned around and headed toward the north/south fairway entrance by then well to his northeast.

4.5.1 Analysis of Dominant Strategy

Figure 26 shows all the tracks in the dominant strategy. Mean track and crosstrack variability does not provide a good measure of what occurred except to show that most subjects maintained their original course even while they doubted their actual position. Only after they were sure of their position, did they maneuver.

From the observation data, it was possible to determine (1) when subjects first doubted their original DR, (2) when they confirmed their error, and (3) how long it took them to resolve their actual position. It was also possible to determine which subjects maneuvered prior to position certainty and the rationale for that maneuver. Of primary concern to the research was how the crew went about handling their dilemma, whether disorientation or confusion occurred (if so, how severe and why), and the appropriateness of the crew's overall response.

4.5.1.1 Analysis of Performance

Performance measures for the degraded DR approach scenario varied somewhat from the previous scenarios. Mean tracks and small crosstrack variability up to the point of maneuver are obvious from the track plots. None were statistically

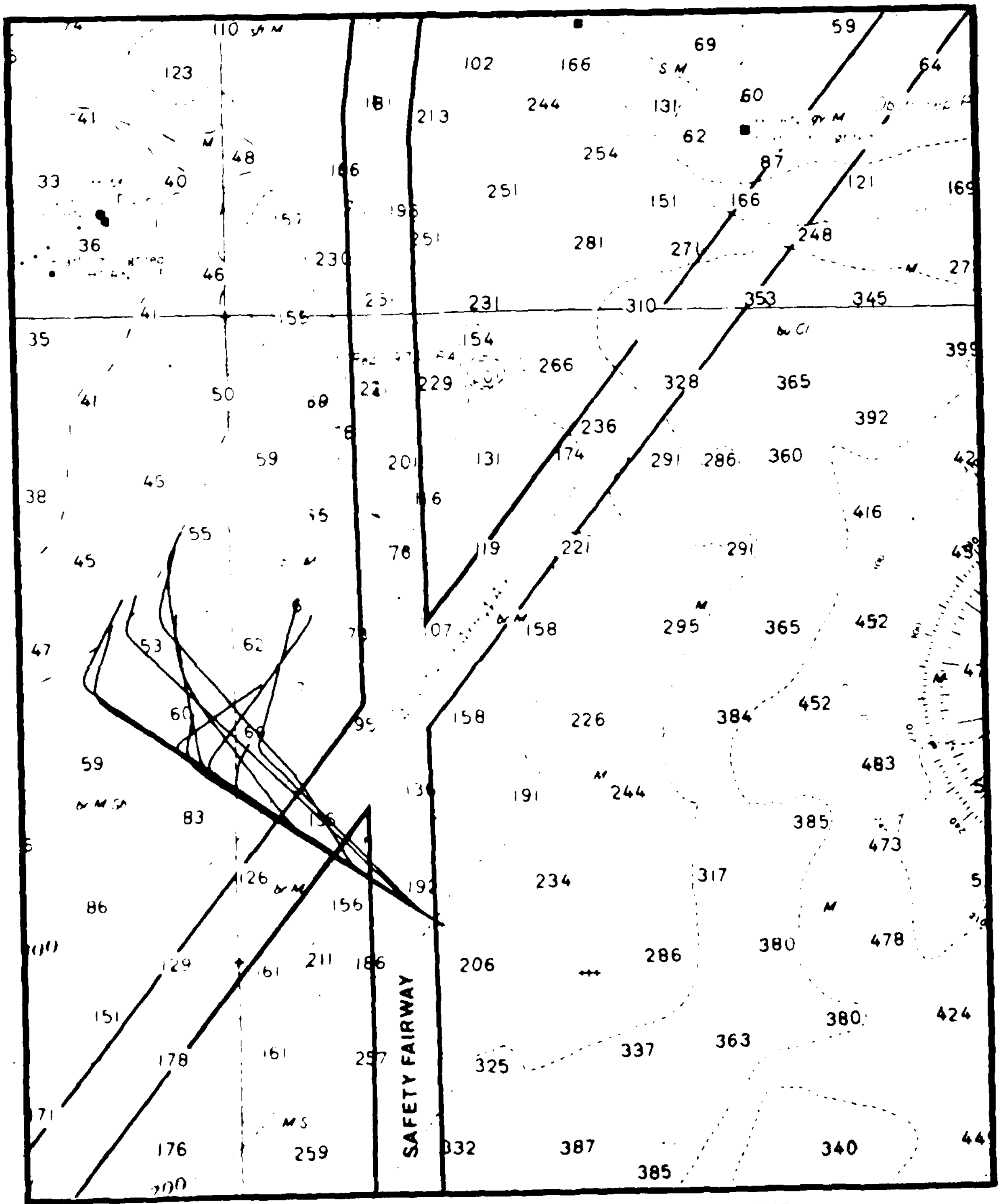

FIGURE 24. INDIVIDUAL SHIP TRACKS DURING THE DEGRADED DEAD RECKONING APPROACH

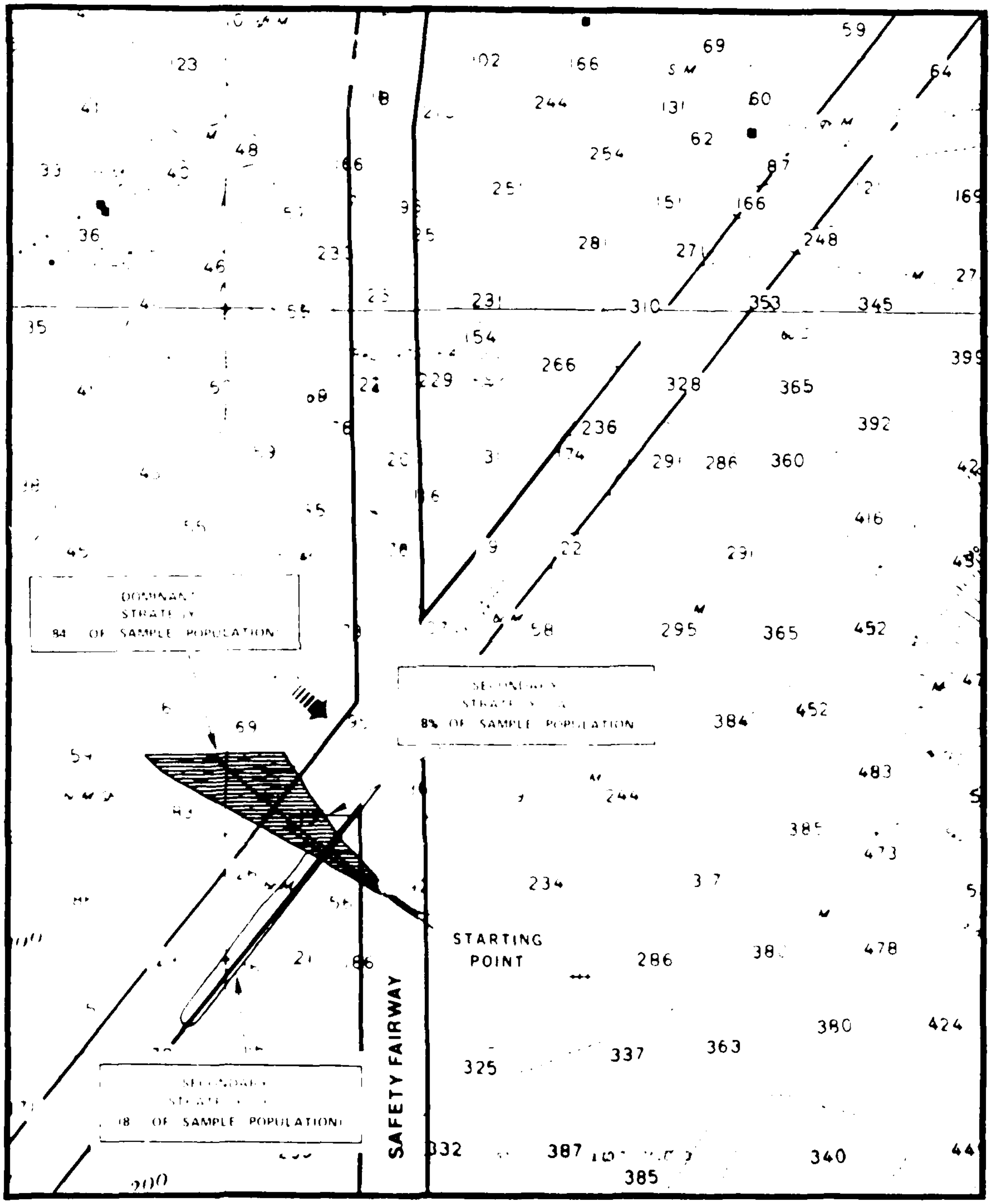

FIGURE 25. THREE STRATEGIES OF THE DEGRADED DEAD RECKONING APPROACH

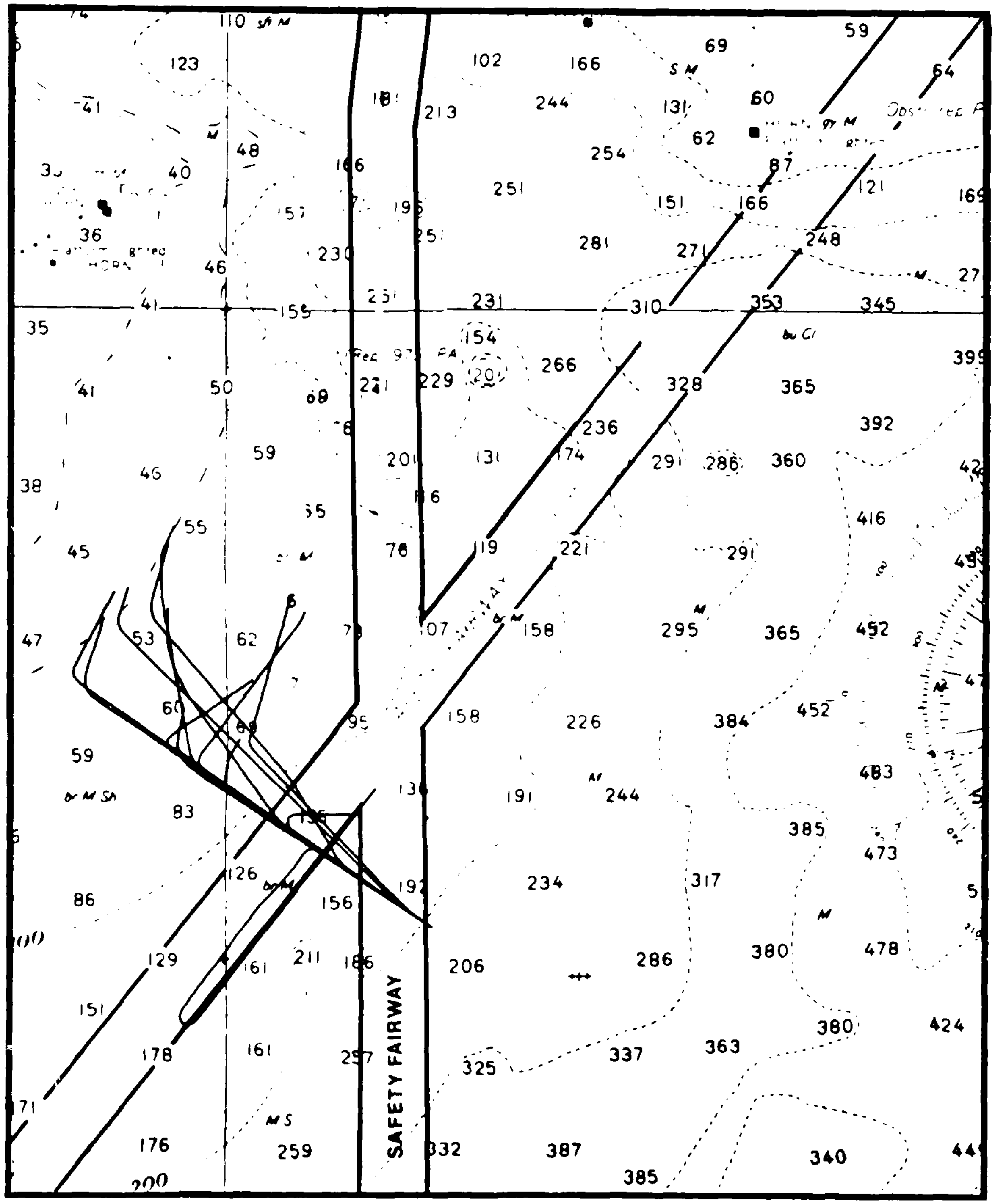

FIGURE 26. DOMINANT STRATEGY OF THE DEGRADED DEAD RECKONING APPROACH

different. The time element (i.e., time to doubt position, time to determine position, time to maneuver, etc.) is employed as an additional measure of pilotage proficiency. Causes for each decision are also included. Performance measures for the dominant strategy of the degraded DR approach scenario are as follows:

1. Mean elapsed time
   - to first doubt original position
   - to confirm erroneous position
   - to determine with confidence actual position
2. Factors contributing to the resolution of position
3. Mean speed and rpm
4. Mean frequency of engine, rudder, and course orders
5. Mean frequency of radar, RDF and Fathometer fixes, and DRs

Note: The single traffic ship within the area was maintained at a distance in excess of 3.5 nautical miles for all subjects and its CPA is not considered relevant to performance.

4.5.1.2 Effect of Display Enhancement on Performance

The analysis of subject performance comparing between radar based and ARPA based displays showed no significant difference in the amount of time required to (1) doubt original position, (2) confirm the erroneous position, or (3) determine actual position (Table 17, lines 1 and 2). Further, the review of track plots, Figures 27 and 28, show no trackkeeping performance or maneuvering technique which can be attributed solely to the use of a radar based or ARPA based display. No significant differences occurred in ship control or navigation workload, Tables 18 and 19 (lines 1 and 2).

In the performance comparison between when individual enhancements were used by all subjects, some differences were indicated. With ARPA and radar/racon, for example, there were significantly fewer rudder orders but more course orders (Table 18, lines 3, 4, and 5) than with radar alone, while overall speed was unaffected. This behavior tends to indicate a higher frequency of steering maneuvering when radar was used; perhaps partial instead of full course changes, and certainly maneuvers with less confidence in a final DR. This rationale is also illustrated in Figure 29 by the more gradual course changes exhibited when radar was used than when radar/racon or ARPA was used.

The previously revealed benefit of racons to augment position fixing cannot be statistically supported in Table 17; nevertheless, trends are indicated (lines 3, 4, and 5) that when racons were used, detection time of the original erroneous DR was reduced by an average of 27 percent (3 minutes), confirmation of the position error by 15 percent (2 minutes), and a determination of actual position by 8 percent (3 minutes). While this is hardly enough improvement to warrant the installation of racons solely for this purpose, it does imply that the racons will be helpful in such situations. Obviously, if ownship had been closer to the racon on the onset of the simulation or if ample time and maneuvering room had not been available to obtain sufficient soundings, value of the racon would have been even more obvious.

In summary, there was no statistical evidence revealed in this experiment to favor one display enhancement over the other in preventing disorientation or in

TABLE 17. REORIENTATION AND POSITION FIXING – DEGRADED DEAD RECKONING APPROACH, DOMINANT STRATEGY

	Mean Elapsed Time (Minutes) to			Maximum Elapsed Time (Minutes) to		
	First Doubt Original Position	Confirm Erroneous Position	Determine Actual Position	First Doubt Original Position	Confirm Erroneous Position	Determine Actual Position
Enhancement Effect						
1. Radar based displays	10	19	39	25	30	55
2. ARPA based displays	9	19	36	20	25	45
3. Radar	11	20	40	25	30	55
4. Radar/racon	8	17	37	10	20	35
5. ARPA	11	19	36	20	30	45
Organization Effect						
6. Traditional organization	11	19	39	25	30	55
7. Team organization	7	18	33	10	25	45
8. Radar based displays - traditional organization	11	20	40	25	30	55
9. Radar based displays - team organization	5	20	30	5	20	30
10. ARPA based displays - traditional organization	10	20	38	20	30	40
11. ARPA based displays - team organization	13	18	35	10	25	45
12. Radar - traditional organization	13	20	43	25	30	55
13. Radar - team organization	5	20	30	5	20	30
14. Radar/racon - traditional organization	8	17	32	10	20	40
15. Radar/racon - team organization	--	--	--	--	--	--
16. ARPA - traditional organization	10	20	38	10	20	38
17. ARPA - team organization	13	18	35	13	18	35

NOTE: No statistical difference at $p < 0.10$ level of significance indicated for any value.

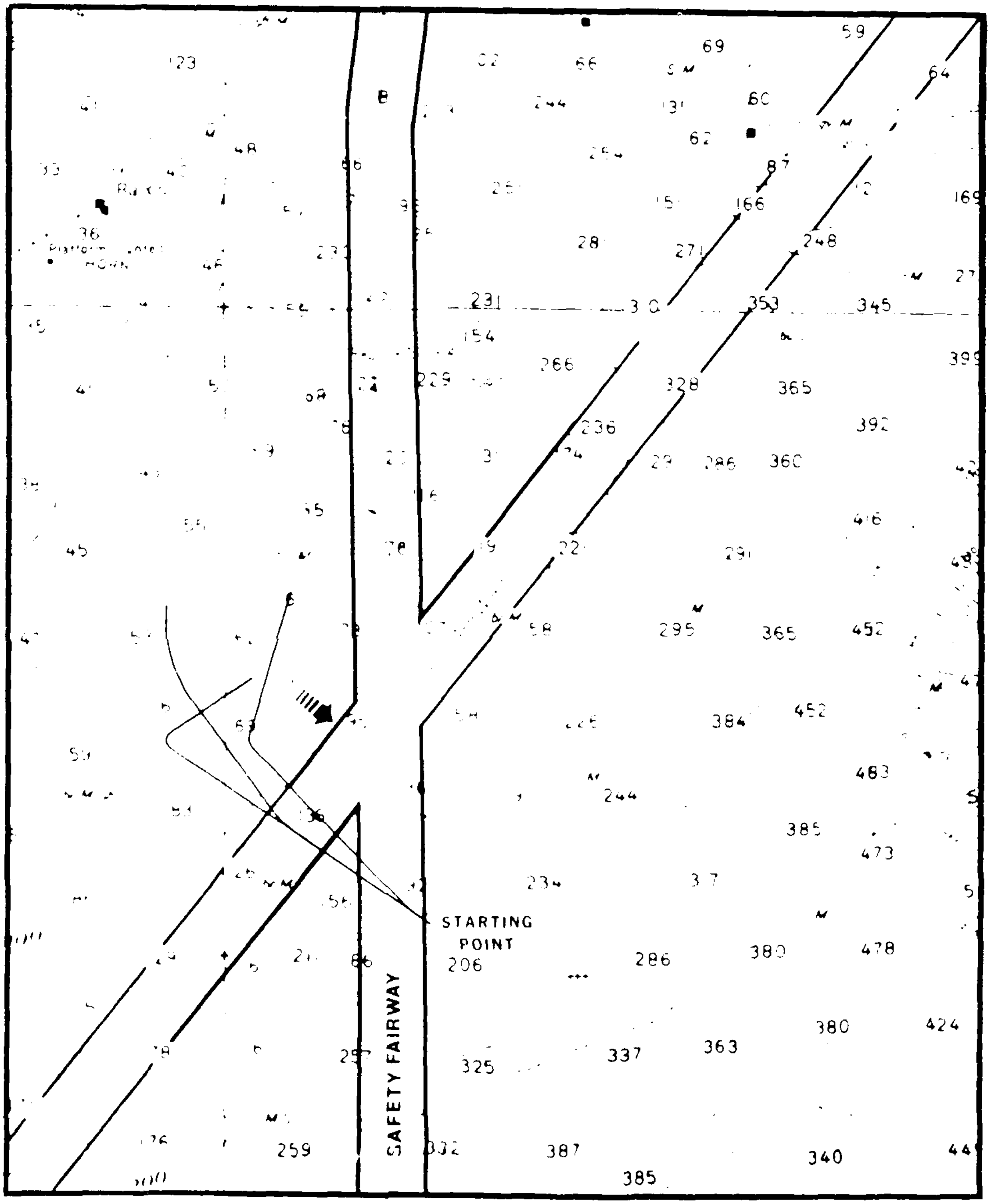

FIGURE 27. DOMINANT STRATEGY TRACKS WITH RADAR/RACON ENHANCEMENT

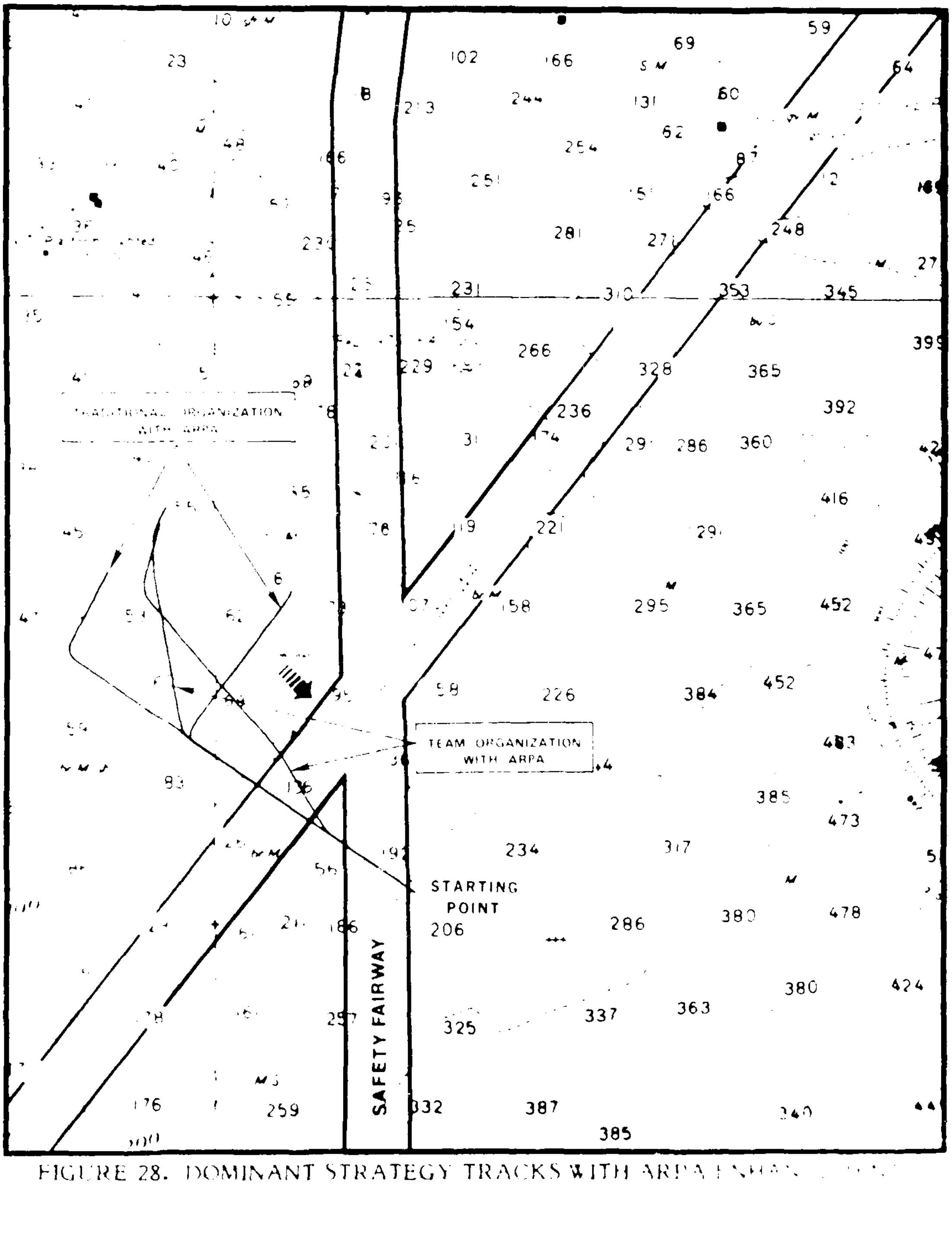

FIGURE 28. DOMINANT STRATEGY TRACKS WITH ARPA [illegible]

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TABLE 18. SHIP CONTROL AND COURSE KEEPING – DEGRADED DEAD RECKONING APPROACH, DOMINANT STRATEGY

Variable	Strategy Mean Speed (knots)	RPM	Engine Orders	Rudder Orders	Course Orders
Enhancement Effect					
1. Radar based displays	14.5	75	0.1	1.4	1.3
2. ARPA based displays	14.3	71	0.5	0.7	1.8
3. Radar	14.2	75	0.0	2.0	0.7*
4. Radar/racon	14.9	76	0.3	0.7*	2.0
5. ARPA	14.3	71	0.5	0.7*	1.8
Organization Effect					
6 Traditional organization	14.6	74	0.4	0.9*	1.2
7. Team organization	13.9	73	0.0	2.0	2.0
8. Radar based displays - traditional organization	15.0	78	0.2	0.7	1.2
9. Radar based displays - team organization	11.7	60	0.0	6.0	2.0
10. ARPA based displays - traditional organization	13.7	61	1.0	1.5	1.5
11. ARPA based displays - team organization	15.0	80	0.0	0.0	2.0
12. Radar - traditional organization	15.1	80	0.0	0.7	0.3
13. Radar - team organization	11.7	60	0.0	6.0	2.0
14. Radar/racon - traditional organization	14.9	76	0.3	0.7	2.0
15. Radar/racon - team organization	--	--	--	--	--
16. ARPA - traditional organization	13.7	61	1.0	1.5	1.5
17. ARPA - team organization	15.0	80	0.0	0.0	2.0

* = statistically different at $p \leq 0.10$ level of significance

TABLE 19. NAVIGATION WORKLOAD –
DEGRADED DEAD RECKONING APPROACH, DOMINANT STRATEGY

Variable	Mean Frequency of Radar Fixes	Loran Fixes	RDF Fixes	Fathometer Fixes	DRs
Enhancement Effect					
1. Radar based displays	5.9	--	3.0	4.7	1.4
2. ARPA based displays	5.8	--	4.5	4.5	0.7
3. Radar	5.8	--	3.0	5.3	1.5
4. Radar/racon	6.0	--	3.0	4.0	1.3
5. ARPA	5.8	--	4.5	4.5	0.7
Organization Effect					
6. Traditional organization	5.4	--	3.5	5.0	1.2
7. Team organization	7.0	--	3.7	3.7	1.0
8. Radar based displays - traditional organization	5.2	--	3.0	4.0*	1.5
9. Radar based displays - team organization	10.0	--	3.0	9.0	1.0
10. ARPA based displays - traditional organization	6.0	--	5.0	8.0	0.5
11. ARPA based displays - team organization	5.5	--	4.0	1.0*	1.0
12. Radar - traditional organization	4.3	--	3.0	4.0*	1.7
13. Radar - team organization	10.0	--	3.0	9.0	1.0
14. Radar/racon - traditional organization	6.0	--	3.0	4.0	1.3
15. Radar/racon - team organization	--	--	--	--	--
16. ARPA - traditional organization	6.0	--	5.0	8.0	0.5
17. ARPA - team organization	5.5	--	4.0	1.0*	1.0

* = statistically different at $p \leq 0.10$ level of significance

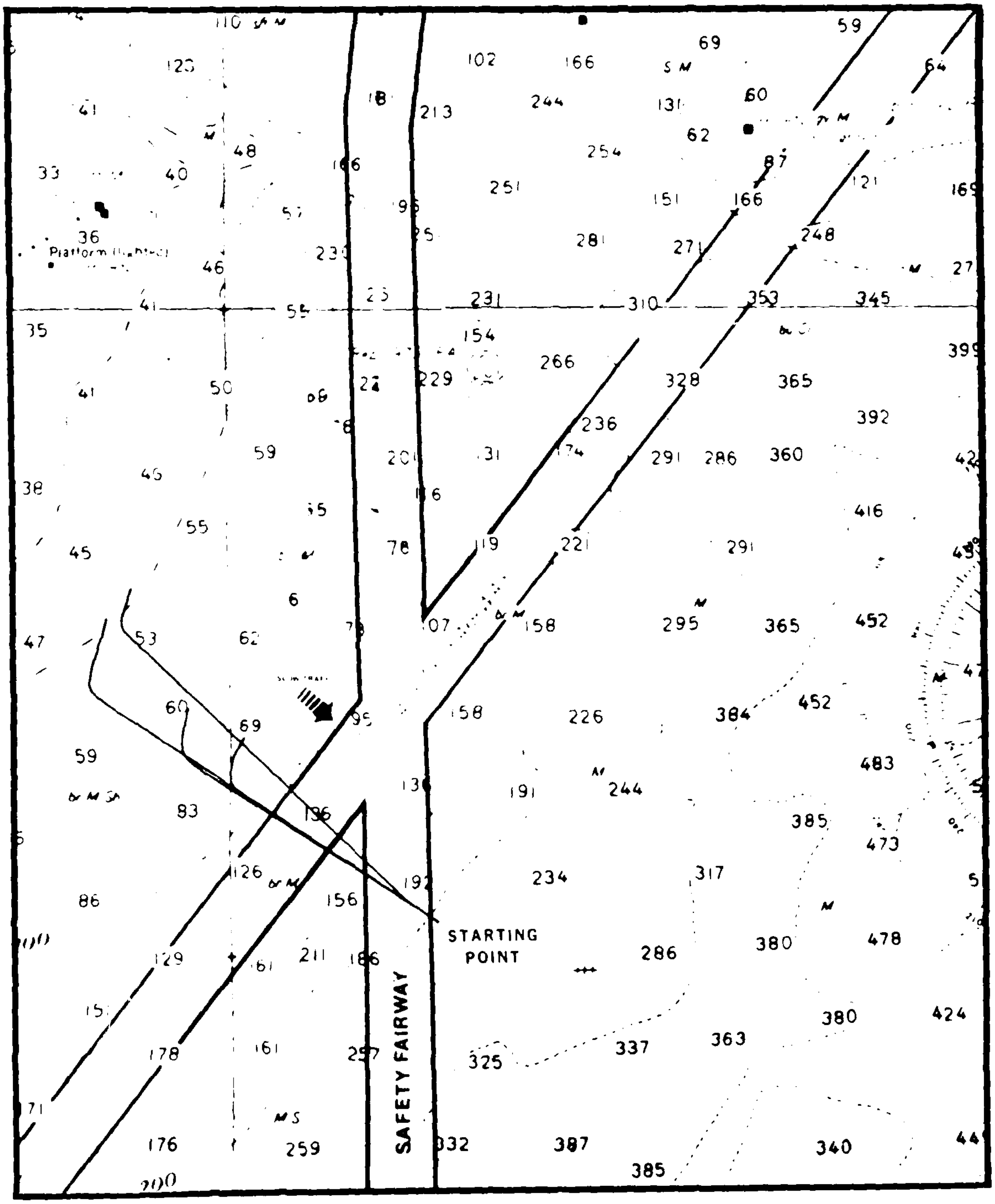


FIGURE 29. DOMINANT STRATEGY TRACKS WITH RADAR ENHANCEMENT

augmenting a determination of erroneous position information. The benefits derived from racons are obvious, since they provided absolute identification and may have contributed to an early detection of the erroneous DR. The benefits derived from ARPA are more difficult to intepret although it is suspected that the ARPA provided an advance clue that the target ahead was a slow moving ship and not a stationary rig as originally interpreted. These conclusions were derived from an analysis of how the navigation problem was resolved. See Table 20. For measures of shiphandling, specifically course changing, significant and comparable benefits of both radar/racon and ARPA were demonstrated.

4.5.1.3 Effect of Bridge Organization on Performance

Table 17 (lines 7 and 8) shows the team organization doubting its original position only 7 minutes into the run compared to 11 mintues for the traditional group. These differences are not statistically supportable; however, a review of the run profile sheets reveals that the team organizations generally did discover the position discrepancy earlier because of their methodical procedures and double checking techniques. Table 18, however, shows the team organization making significantly more rudder orders than the traditional group. These results prompted a closer scrutiny of enhancement/organization interaction effects.

4.5.1.4 Effect of Enhancement/Organization Interaction on Performance

Performance differences are apparent for the degraded dead reckoning scenario when comparing bridge organization of subjects using the radar based enhancements. Table 17 (lines 8 and 9) shows the team organization suspecting an erroneous DR over 50 percent (6 minutes) sooner than the traditional group; and while they confirmed this error in comparable time, they were then able to determine their actual position 25 percent (10 minutes) earlier. It must be acknowledged that the sample size is not adequately large to support statistical conclusions; nevertheless, the difference is noteworthy in light of the anticipated manning and equipping of ships for the deepwater port operation. A review of Table 19 shows that when they used the radar based displays (including racon), the team organization took significantly more Fathometer fixes and considerably (though not statistically significant) more radar fixes. RDF fixes in this scenario which was conducted without loran were consistently frequent for all organizations and all enhancements.

With ARPA the team organization took significantly fewer Fathometer fixes (Table 19, lines 16 and 17). Resultant tracks show one unique difference between organizations with ARPA although it is thought to be the result more of individual preference than attributed to the enhancement/organization interaction. Figure 28 shows both organizations all arriving on about the same new course. Note that with the traditional organization, as soon as actual position is confirmed one single maneuver is executed. With the team organization, several course changes are executed sometimes before ownship's position is confirmed. This interim leg was steered primarily by the team organization using rudder commands, with the result that the team organization had significantly more rudder commands for the overall scenario than the traditional organization. The measure, therefore, serves only to indicate what occurred and not how appropriately it occurred.

To adequately summarize the performance achieved in the dominant strategy and to compare display enhancements and bridge organization, the measures just

TABLE 20. FACTORS IN THE RESOLUTION OF ACTUAL POSITION FOR THE DOMINANT STRATEGY

Variable	What Provided First Cue of Erroneous DR	How Was Erroneous DR Confirmed	How Was Actual Position Determined
Radar	Initial suspicion of old DR; incompatibility of RDF fix with sounding	RDF fixes and soundings	Line of soundings and RDF fix
Radar/racon	Incompatibility of racon fix with DR	Racon fixes and soundings	Racon fix, RDF fix and sounding
ARPA	Incompatibility of ARPA display with DR	RDF fixes and soundings	Compatibility of rig patterns with RDF fixes
Traditional organization	Initial suspicion of old DR; incompatibility of RDF fix with sounding	RDF fixes and soundings	Line of soundings, radar and RDF fix
Team organization	Initial suspicion of old DR; incompatibility of RDF fix with sounding	RDF fixes and soundings	Line of soundings, radar and RDF fix

discussed must be put into proper context. Since the primary purpose of this scenario was to determine what effect the variables would have on reorientation and position fixing, that single measure alone should provide a majority of rationale for the conclusion of performance. Briefly, it was shown (Table 17) that in all runs regardless of enhancement or bridge organization:

1. Original position was first doubted at between 5 and 25 minutes into the simulation;

2. Erroneous position was confirmed at between 20 and 30 minutes into the simulation (an average of 11 minutes later); and

3. Actual position was determined at between 30 and 55 minutes into the simulation (an average of 20 minutes after the error confirmation.

In light of the speed with which ownship was traveling, the lack of immediate danger from hazards or shallow water, and the navigation requirements imposed upon the subjects, this particular resolve of the disorientation problem signifies acceptable performance. Other criteria such as ship control and course keeping, navigation workload, and the means by which the problem was resolved are important but tend only to reinforce the conclusion that such a situation could be comparably handled regardless of display enhancement or bridge organization. Maneuvers for the recovery of an otherwise potentially dangerous situation were unique as a function of individual preference, but all would result in a safe and expedient course to the deepwater port complex.

4.5.2 Analysis of Secondary Strategies

Two secondary strategies are addressed in the degraded dead reckoning approach scenario. They are shown in Figure 25. Both secondary strategies represent impractical and possibly artifical responses to a situation which does not require such an extreme solution. Both are reported, however, since they do represent potential behaviors in an approach to a deepwater port. Neither, it is emphasized, jeopardized the vessel's safety and, in fact, were probably the result of over-cautiousness. A brief description of both secondary strategies was presented in Section 4.5.

4.5.2.1 Analysis of Performance

To compare performance exhibited in the dominant strategy with that of the secondary strategies of the degraded dead reckoning approach, performance measures and analysis identical to the dominant strategy were employed. Small sample size of the secondary strategies prevented a statistical comparison of many measures; nevertheless, available data are presented in Section 5 (Table 25).

4.5.2.2 Effect of Display Enhancement and Bridge Organization on Performance

Secondary strategy "A" is shown in Figure 25. It was considered distinctive from the dominant strategy because of the master's decision to return to the north/south fairway entrance instead of proceeding north to the complex as 84 percent of all other masters had done. No significant difference in trackkeeping was indicated between secondary strategy "A" and the dominant strategy up to the point of maneuver. While this could be attributed to the small sample size, a review of Figure 24 suggests that the secondary strategy was, in fact, very similar up to the point of maneuver. Secondary strategy "A" occurred with a team organization using the radar/racon enhancement. While it is acknowledged that the racon aided the subject in initially determining his position, the racon was not the cause of his action. Instead, observations show that the subject misinterpreted the course of the "slow traffic" ship ahead and turning to pass astern, found himself in a long stern chase. It is concluded that use of the racon was helpful in the reorientation phase of the scenario, but that due to a deficiency of the subject's radar plot, the resultant response should not be considered characteristic.

Secondary strategy "B" is shown in Figure 25 but not statistically described in Section 5 (Table 25) due to its extreme departure from the anticipated normal track. This strategy, however, must be acknowledged as a potential alternative to continuing on course while attempting to determine position. A review of observations shows that the secondary strategy "B" subject considered several other maneuver alternatives before turning southwest. One difference between secondary strategy "B" and the other strategies was in the mean lapsed time to determine actual position. As opposed to the other strategies which averaged 38 minutes (range 25 to 55 minutes) to determine actual position, secondary strategy "B" took 90 minutes. This delay was caused by the subject's direction away from the rigs, thus reducing his probability of pattern recognition and, in effect, decreasing his availability of navigation information. This particular strategy would be expected to occur infrequently in an approach, although it is acknowledged that not only was it conducted safely, but it resulted in the subjects finding his position with complete certainty.

4.5.3 Overview

Table 21 represents a brief summarization of the analysis of performance for the degraded dead reckoning approach scenario. An additional discussion comparing strategies and scenarios is presented in Section 5. It concludes that all strategies were conducted safely and that disorientation or major navigation errors were not experienced in the approach to a deepwater port. All conclusions which were derived from the chain of evidence could be generalized to near inshore ports or offshore ports in areas other than the Gulf of Mexico.

4.6 ANALYSIS OF QUESTIONNAIRES AND SUBJECTS' RECOMMENDATIONS

Questionnaires were administered to the subjects before and after each simulation to supplement the quantitative analysis. A prerun questionnaire identified the master's planned strategy before the ship was actually underway and was used for determining and categorizing strategies. The postrun questionnaire was administered as a self-evaluation of performance. Both questionnaires are presented in Appendix C. The information from them was used for developing the run profile sheets from which descriptive data could be extracted.

4.6.1 Summary of Responses to the Postsimulation Questionnaire

The following conclusions were derived from the analysis of questionnaire responses. They are discussed in conjunction with Table 22, the actual questionnaire results.

TABLE 21. SUMMARY OF DEGRADED DEAD RECKONING APPROACH PERFORMANCE

- Of the potential techniques for recovering from degraded navigational information on an approach to a deepwater port, the most likely to occur is described by the dominant strategy of the experiment.
- The alternative strategies and, in fact, even the existence of alternative strategies for recovering from the degraded dead reckoning approach are not shown to be a function of type of display used or bridge personnel organization. Further, they would be expected to occur with low frequency in a deepwater port operation.
- All runs were conducted using accepted shiphandling procedures and navigation techniques for a subsequent determination of actual position and the safe establishment of a course toward the deepwater port complex.
- In general, subjects did not deviate from their original erroneous DR until the time they had confirmed their actual position.
- All subjects altered course immediately upon determining actual position.
- Course alterations to the deepwater port complex were executed so as to minimize the maneuver and yet enter the north/south fairway prior to arriving at the deepwater port.
- There is no indication, statistical or otherwise, to suggest that the type of recovery maneuver or new course selected to the complex occurred as a function of display enhancement or bridge organization. Personal preference seemed to dominate this decision.
- Racons were shown to aid both in confirming an erroneous position and in determining actual position once they were within radar range.
- There is evidence that time to confirm the erroneous DR was reduced with ARPA by the display of motion on the "bogus rig" ahead and with racons by their absolute identification.
- It is concluded that ARPA/NAV would provide additional navigational confidence providing it correlated with peripheral information such as rig positions aids to navigation.
- Population sample size was inadequate to statistically test display enhancement/bridge effects; however, there are trends in performance to suggest when only radar was used, team organizations may have (1) suspected the erroneous DR earlier and (2) determined their actual position earlier than the traditional bridge organization.
- At no time, with no display enhancement or bridge organization, did functional disorientation (loss of reasoning and logical process) or extreme anxiety occur for any subject. Further, although many subjects acknowledged that they were temporarily "lost" (sic), none considered their situation dangerous or irreconcilable.

TABLE 22. SUMMARY OF QUESTIONNAIRE RESULTS

Topic	Question	Response
Enhancements	Subjects were asked to rank enhancement by most effective navigational tool	• 41% chose ARPA/NAV • 28% chose radar with racons • 21% chose ARPA • 10% chose radar only
	Would subjects use ARPA in an actual situation	• 92% said definitely • 8% said may or may not
	When asked to compare radar alone to radar with additional racons	• 77% said it added much significant information • 23% said it added significant information
	When asked if the scope representations were significantly realistic	• 92% stated yes • 8% stated no
Scenarios	When asked which scenario was easiest	• 53% chose the landfall approach • 25% chose the pilot area approach • 22% chose the coastwise approach
	When asked which scenario was most difficult	• 49% chose the pilot area approach • 31% chose the coastwise approach • 10% chose the landfall approach
	Would subjects have conducted all transits under similar conditions on an actual ship	• 85% said yes • 15% said no
	Did the lack of visibility affect the subjects' transits	• 69% stated yes • 31% stated no
Ownship	Have the subjects previously handled a similar ship at sea	• 100% answered yes
	Did the subjects feel the ship's maneuvering response was realistic for its size, type,and loading condition	• 100% answered yes
Navigation Conditions	Were the charts provided adequate	• 85% responded yes • 15% responded no
	Was the navigation information provided during the scenario adequate	• 100% responded yes

TABLE 22. SUMMARY OF QUESTIONNAIRE RESULTS (CONTINUED)

Topic	Question	Response
General Simulation	Was the bridge equipment adequate	• 100% said yes
	When asked if the bridge equipment functioned properly and if its arrangement was characteristic of a "typical" merchant ship bridge	• 69% responded yes • 31% responded no
	Subjects' simulation experience	• 62% had previous experience • 38% had no previous experience
	Subjects were asked if the simulation felt natural on the first transit	• 81% responded yes • 19% responded no
	Subjects were asked if after 2 or 3 runs they recognized elements of the situation	• 100% answered yes
	Subjects were asked if they were able to adapt to the simulator so responses were the same as they could be at sea	• 100% answered yes

4.6.1.1 Display Enhancement

The majority of the masters preferred ARPA with the navigation option (ARPA/NAV), followed by ARPA, then radar with racons. Radar without racons was rated as the least effective navigation tool. This was determined by weighting each subjects ranking of the displays. Those subjects who chose ARPA with the navigation option did so because they could easily distinguish between fixed and moving contacts in relation to the fairway boundaries. The subjects liked the tracking capability and the presentation of information which could easily be transferred between the display and the chart. The subject who chose ARPA preferred this enhancement because moving targets could be sorted out on the screen. He did not believe the fairway boundaries added any significant information. Those subjects who preferred radar with racons felt this was the best method of establishing ownship's position under adverse conditions particularly since the radar display was most familiar and because few operating adjustments would be required.

Over 90 percent of the subjects stated they would use an ARPA display in the real world; however, only 38 percent of the subjects stated that the fairway boundaries added necessary information. When comparing radar alone to radar with racons, 77 percent of the masters stated that the racons added significant information to the radar display.

Over 90 percent of the subjects stated the display representations were sufficiently realistic; however, one subject stated that a bearing line should have been provided on the radar since it is helpful during navigation.

4.6.1.2 Scenario Design

Fifty-three percent of the subjects stated that the landfall approach scenario was the easiest because of ownship's position at the beginning of the scenario. Once the traffic had passed ownship, the approach was straight forward because there were few rigs of concern and ownship could easily enter the fairway.

Fifty percent of all subjects stated that the approach and drift scenario was the most difficult because of the lack of offshore navigation aids and the time constraint to meet the mooring master. Subjects found it difficult to make a large turn at a very low speed and to be stopped at the pickup point without entering the precautionary area. Forty percent of the subjects stated that the coastwise approach scenario was the most difficult because of traffic in the fairway.

Eighty-five percent of the subjects would have conducted the transits similarly on an actual ship, however, some subjects would have travelled at a slower speed under similar visibility conditions. One subject would have originally taken a more southerly route from Mobile, Alabama to avoid the entrance to the Mississippi River. Another stated that he came too close to the rigs for foggy conditions and should not have done so.

Approximately 70 percent of the subjects said the lack of visibility affected their transits because a more cautious approach was required. Two subjects indicated they should have reduced speed even further.

4.6.1.3 Ship Type

All subjects had handled a similar ship at sea, and all stated that the ship maneuvering response was realistic for its size, type, and load condition.

4.6.1.4 Navigation Conditions

All subjects stated that the navigation information provided during the scenarios was adequate; however, 15 percent thought the charts could be improved by a larger scale of the deepwater port area and by extending the chart further south.

The most frequent recommendation for improving the navigational aids was to add racons or radar reflectors at various locations. These are listed in the order in which they were deemed important: (1) at junction of N/S fairway (2) marking the E/W fairway either at S/W pass or rig southwest of S/W pass, (3) on one of the buoys marking the precautionary area, and (4) on outer northeasterly corner of the N/S safety fairway. Other recommendations included placing a lower powered RDF station on the LOOP platform or a buoy to mark the jog in the fairway.

The most frequent recommendation for improvements of the channel configuration was to provide a safe anchorage area close to the precautionary area that could be used without the mooring master onboard. Subjects also recommended the anchorage area be enlarged and repositioned to eliminate the dog leg turn. Several subjects recommended the jog in the fairway be eliminated. An alternative to these changes would be to move the mooring master pickup point further south so the turn could be made with the mooring master onboard the ship. Two subjects recommended the fairway be widened and a traffic scheme be developed and indicated on the chart.

4.6.1.5 General Simulation

All but one subject stated the bridge equipment was adequate. Seventy percent of the subjects stated the simulator functioned properly and its arrangement was characteristic of a "typical" merchant ship. Those who did not said the steering wheel should have been in the center with the radars on the side and the turn rate indicator should have been in minutes rather than seconds. All agreed that these factors did not affect the validity of the experiment.

Over 60 percent of the subjects had previously used a ship simulator, and all but two subjects said that the simulation felt natural on the first transit. The two subjects who felt uncomfortable needed only one run to become comfortable with the ship.

An additional recommendation made by one subject was that the U.S. Coast Guard should strongly recommend simulator training for deepwater port approaches. Another stated that the repeated runs were not challenging, and more traffic should have been included. A third subject stated that more set and drift should have been applied because of its effect on piloting a fully loaded VLCC. A validated set and drift was present in all simulations, but occasionally was not recognized by the subjects.

4.6.2 Overview

Table 23 presents a summary of masters' recommendations. In general, while their opinions were subjective, it must be remembered that all were qualified VLCC masters, some with extensive experience in transiting the LOOP area. As a result, it is suggested that individual recommendations be carefully considered and, in light of the performance revealed by the experiment, these recommendations be proposed as alternative solutions to the identified problems.

TABLE 23. SUBJECT RECOMMENDATIONS

Traffic Regulations

- Assign one-way fairways.
- Establish two-way separation lanes for traffic. This should be indicated on the chart by a centerline in the fairways.

Anchorage Area

- Enlarge the anchorage to double its current size.
- Designate an anchorage area open to ships west of the fairway.
- An anchorage should be established for holding during an extended period that would be open to all masters without a deepwater port representative onboard ship.

Required Publications

- A port operations manual should be developed with recommended approach procedures and charts designating pipelines, rig patterns, and useful aids to navigation.

Changes in Fairway Configuration

- Provide a safe anchorage area close to the precautionary area that could be used without the mooring master onboard.
- Anchorage area be enlarged and repositioned to eliminate the dog leg turn.
- Fairway jog should be eliminated.
- An alternative to these changes would be to move the mooring master pickup point further south since maneuvering should be avoided at the very low speeds required for this operation.
- The fairway should be widened and a traffic scheme developed and indicated on the chart.

Changes in Aids to Navigation

- Add racons or radar reflectors at various locations: (1) at junction of N/S fairway, (2) marking the E/W fairway either at S/W pass or rig southwest of S/W pass, (3) on one of the buoys marking the precautionary area, and (4) on outer northeasterly corner of the N/S safety fairway.
- Place a lower powered RDF station on the pumping platform and a buoy to mark the fairway jog.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 RESEARCH QUESTIONS

This section draws together the categories of evidence from the research program into a summary of significant findings and conclusions. It is meant to focus the specific findings of Section 4 to the general issue of VLCCs approaching an offshore deepwater port during periods of low visibility.

The original basic research questions were:

1. What combination of hazards, if any, present serious precision navigation problems to VLCC masters in the vicinity of a deepwater port?

2. What mitigating measures appear most practical in terms of effectiveness, timing and ease of implementation?

3. What is the value of potential electronic aid enhancements for general application to offshore and shoreside ports?

5.2 CATEGORIES OF EVIDENCE

To answer these questions, a broad based research program was developed which would provide a variety of data to characterize and evaluate VLCC operations during poor visibility approaches to an offshore deepwater port. The categories of data included:

- Review of the hazard and risk assessment analysis performed for the Coast Guard.
- Presimulation interviews with VLCC masters and mates to characterize the navigation process, obtain subjective assessment of hazards and risks, and develop believable and productive simulation scenarios.
- Quantitative, automatically and manually recorded data collected during the real time simulation experiments using practicing VLCC operators as test subjects.
- Statistical analysis comparing subjects' ship control and trackkeeping performance, navigation workload, and hazard avoidance.
- Descriptive run profiles derived from observers' research notes and subject questionnaire responses.

Generally, the data can be considered to either be descriptive or inferential. The descriptive data included all data from the questionnaires, research notes, and simulation observations and the individual ship tracks. Descriptive data told the story of the research. They documented observations, indicated trends, and highlighted areas for analysis. In addition, they provided the logical support structure for the inferential evidence.

Inferential evidence was developed by the measurement of performance and application of standard statistical tests, specifically an analysis of variance and F-statistics. This inferential evidence led to statistically supportable conclusions. While the research attempted to derive support for conclusions from both types of data, certain behaviors were not revealed in the statistics. In these instances, the descriptive data were reported, and whatever inferential data were available contributed to the logical chain of evidence.

5.3 CONCLUSIONS ON THE SAFETY OF NAVIGATION IN DEEPWATER PORT APPROACHES

There is no evidence on the basis of this research which suggests that approaches of VLCCs to an offshore deepwater port are deceptively difficult. Even though the simulation experiment presented some navigational and traffic situations which could have resulted in difficulties for the VLCC masters, no difficulties were encountered which are attributed to the design or operation of the deepwater port as it was simulated.

Maximum freedom of choice was given to the VLCC operators to select their approach strategy from the starting point. This feature of the research design resulted in a number of opportunities to discuss safety related issues also applicable to near inshore ports or offshore ports in areas other than the Gulf of Mexico.

5.3.1 Landfall and Coastwise Approaches

Development of the simulation research plan began with a review of the hazard and risk assessment study and an at-sea navigation task analysis. Concurrently, interviews were conducted with VLCC masters to obtain a prior assessment of vessel transit patterns associated with a Gulf of Mexico deepwater port. The findings on issues relating to safety of the transit conclude:

- Safety fairways would be used routinely if they offered a reasonable track from the ship's point of departure.
- Considerable coastwise navigation would be conducted outside of the fairways to make a more direct transit of the Gulf of Mexico.
- Long-range navigation techniques such as loran, satellite and celestial navigation would be used until an identifiable landfall was made. The radar patterns and individual fixed structure locations would be used as primary aids during the final phases of the approach.
- A minimum clearance of 0.5 to 2.0 nautical miles would be maintained to charted offshore structures. The lack of visibility does not appear to be a major concern.
- High traffic levels were universally assessed as the most significant hazard associated with a port approach.
- The approach to a Gulf of Mexico deepwater port would not be difficult, and local aids to navigation would be adequate for routine transits.

The hazard and risk assessment study identified personnel fault and heavy weather as the principal hazards to navigation. Offshore rigs, vessel traffic, and low visibility were identified as additional hazards but were judged to be lesser risks.

The navigation function analysis indicated exclusive reliance on long-range navigation aids and techniques during open-sea operations. Radar, however, appeared to be the primary navigation tool used in U.S. coastwise operations.

Two simulation scenarios were developed as a result of the preplanning process to examine the transition from open sea and coastwise approaches to a deepwater port safety fairway. Twenty-four simulation transits were conducted through each scenario to develop information on likely approach strategies and safety of the transits. Each scenario was constructed in such a way as to offer approach strategy options to the experimental subjects.

Analysis of the simulation runs revealed that:

- During the landfall scenario when an approach into the safety fairway was generally adjacent to the vessel's track, 76 percent of the masters adjusted course and entered at the intersection of the safety fairways.

- In the landfall scenario, 24 percent of the masters were not concerned with entering the safety fairway. They set their objective in terms of expediency and "convenience" (sic) rather than fairway compliance. It should be noted that there were no rigs, traffic, or shoal areas immediately outside the fairway that would have made the outside transit unsafe.

- During the coastwise approach, three different strategies were observed. Sixty-eight percent of the subjects crossed the Gulf east/west safety fairway, passing south of rigs and obstructions and entered the north/south safety fairway near the 100 fathom curve.

- Sixteen percent entered and remained in the east/west safety fairway even though the transit was lengthened by about an hour.

- Sixteen percent maneuvered through a gap in the rigs, and found a clear path along the most direct course to the port through the lease blocks.

Table 24 summarizes the recorded hazard avoidance measures for the simulation transits.

- CPAs to fixed rigs exceeded 0.95 nautical mile under all conditions with means on the order of 2.0 to 2.5 nautical miles.

- CPAs to traffic were lowest when ships passed on parallel headings in the safety fairway. This would be expected in light of the predictability of masters' intentions when passing close aboard in meeting or overtaking situations.

- The debriefing interviews support the observed data. Eighty-five percent of the subjects stated that they would have conducted the transits similarly aboard ship under these conditions. Only the one subject who passed a ship at 1.7 nautical miles stated that he had passed too close to traffic.

TABLE 24. HAZARD AVOIDANCE FOR ALL DISPLAY ENHANCEMENTS AND ALL BRIDGE ORGANIZATIONS

	Mean CPA to:		Lowest CPA to:	
	Traffic Ship Close Aboard	Traffic Ship Crossing	Traffic Ship Close Aboard	Traffic Ship Crossing
1. Entire landfall approach	1.25	2.44	1.02	1.32
2. Dominant strategy	1.24	2.57	1.02	1.68
3. Secondary strategy "A"	1.25	1.79	1.25	1.32
4. Secondary strategy "B"	1.29	2.27	1.26	1.62

	Mean CPA to:			Lowest CPA to:		
	Traffic Ship Close Aboard[1]	Maneuver Around Rig	Pass Abeam Rig	Traffic Ship Close Aboard[1]	Maneuver Around Rig	Pass Abeam Rig
5. Entire coastwise approach	1.90	2.41	2.53	0.17	0.95	0.99
6. Dominant strategy	1.37	2.21	2.77	0.53	0.95	0.99
7. Secondary strategy "A"	3.37	1.82	2.51	3.07	2.29	1.51
8. Secondary strategy "B"	0.58	--	--	0.17	--	--

[1]Different traffic ships are represented for different scenarios and strategies.

Table 25 contains the shiphandling and navigation task summary for all scenarios. The results for the landfall and coastwise approaches (lines 1 and 2, and 5 through 10) indicate that:

- No significant differences in overall shiphandling and navigation technique were found between landfall and coastwise scenarios or among the individual strategies.

- Radar and loran were the primary means of fixing positions for the landfall and coastwise approaches.

- Although the average use of radar for navigation was identical between scenarios, 50 percent more loran fixes were observed during the landfall approach. This is supportive of previously obtained at-sea data which suggest that operators will use radar as a primary means of navigation when identifiable rig patterns or aids to navigation are continuously available.

5.3.2 Mooring Master Pickup Approach

VLCCs maintain considerable inertia and become more sluggish in response to helm and engine orders at slow speeds. Concern was expressed that the phase of the approach involving slowing and maneuvering a VLCC in the vicinity of the mooring master pickup area might lead to disorientation affecting safety of the transit. Consequently, a scenario was developed to examine this phase of the deepwater port approach. Ownship was located in the safety fairway approximately 7 miles from the mooring master pickup point, on a course to the north and at speed of 10 knots. Twenty-four simulation transits were conducted through that scenario to develop data on likely approach strategies and the safety of the transits. The objectives of the scenario were to:

1. Examine user strategies during the approach to a mooring master pickup point.

2. Observe operators' strategies, position keeping techniques and shiphandling performance in the event of brief delays by the mooring master's launch.

3. Determine the contingencies that would be expected in the event of extended delays of mooring masters.

- The dominant strategy which was demonstrated in 92 percent of the transits was to slow the ship by reducing rpm soon into the run and maintain a direct course to the pickup point. At the end of the approach, a maneuver was made to position the ship to receive the mooring master.

- Additional strategies which were observed involved the use of rudder cycling and hard rudder maneuvers to slow the ship. These more aggressive shiphandling maneuvers were caused by a perception that the initial speed of the ship was excessive for this phase of the approach transit.

- No difficulties were observed in fixing position during this phase of the transit. A variety of rig patterns were visible on the radar, and the port complex and precautionary area buoys were distinctive on the display.

TABLE 25. SHIPHANDLING AND NAVIGATION FOR ALL DISPLAY ENHANCEMENTS AND ALL BRIDGE ORGANIZATIONS

	Approach Mean					Mean Frequency per NM[1]				
	Speed (knots)	RPM	Engine Orders	Rudder Orders	Course Orders	Radar Fixes	Loran Fixes	RDF Fixes	Fathometer Fixes	DRs
COMPARISON BETWEEN SCENARIOS										
1. Landfall approach	14.4	78	0.02	0.37	0.32	0.39	0.26	0.06	0.11	0.25
2. Coastwise approach	14.5	78	0.03	0.13	0.35	0.39	0.18	0.05	0.08	0.28
3. Pilot area approach	7.7*	21*	0.80*	0.37	0.44	1.26*	0.17	0.00	0.11	0.43*
4. Degraded dead reckoning approach	14.1	74	0.06	0.28	0.33	1.28*	--	0.68*	0.95*	0.21
COMPARISON BETWEEN STRATEGIES										
Landfall approach										
5. Dominant strategy	14.3	77	0.03	0.47	0.31	0.41	0.28	0.05	0.11	0.24
6. Secondary strategy "A"	14.9	79	0.00	0.05	0.44	0.36	0.26	0.14	0.09	0.23
7. Secondary strategy "B"	15.0	80	0.00	0.05	0.26	0.33	0.14	0.5	0.09	0.35
Coastwise approach										
8. Dominant strategy	14.3	76	0.03	0.14	0.40	0.65	0.21	0.03	0.11	0.35
9. Secondary strategy "A"	14.6	78	0.04	0.01	0.21	0.52	0.04	0.04	0.00	0.21
10. Secondary strategy "B"	15.0	80	0.00	0.20	0.29	0.38	0.18	0.00	0.00	0.08
Pilot area approach										
11. Dominant strategy	7.8	20	0.70	0.32	0.44	1.35	0.16	0.00	0.12	0.42
12. Secondary strategy "A"	6.2	9	2.60	1.40	0.20	0.13	0.20	0.00	0.00	0.60
13. Secondary strategy "B"	7.7	39	1.41	0.60	0.60	0.11	0.40	0.00	0.00	0.40
Degraded dead reckoning approach										
14. Dominant strategy	14.5	74	0.06	0.23	0.29	1.11	--	0.67	0.89	0.23
15. Secondary strategy	15.1	79	0.00	0.79	0.79	3.15	--	0.79	1.58	0.00

* statistically different at $p < 0.10$ level of significance

[1] The standard measure of absolute mean found in all other tables has been converted to a "per nautical mile" value to provide a relative comparison of performance between scenarios and strategies of unequal length and/or duration.

- Position fixing frequency increased during the approach transit, and loran positioning frequency remained equal to the coastwise transits.

- In response to notification that the mooring master would be delayed, the individual masters chose to drift, circle slowly, maneuver in a slow race track within the safety fairway, or direct the ship back down the fairway until a definite pickup could be arranged.

- When the delay was extended, the responses were continued drifting, slow steaming in the fairways, leaving until the port was available, and anchoring inshore or south of the port complex. All represented a continuation of the response selected at the initial notification of the mooring master delay.

- While there were differences in individual subject responses to the mooring master delays, the analysis shows that all responses were consistent with findings of the presimulation interviews, and occurred as a function of individual preference. There was no correlation of any of these responses with a specific bridge organization or display enhancement.

Of major interest in this scenario was the range of masters' and mates' suggestions regarding potential port improvements. A variety of specific recommendations is presented in Section 4.6, and it is suggested that particular consideration be given to:

- Boarding vessels in a straight fairway segment rather than asking the master to slow and position his ship immediately after a turn. This would eliminate the need for a major maneuver at slow speed in the dogleg.

- Designating a holding anchorage in the vicinity of the port which vessels can enter without a mooring master aboard. Delays as a result of weather, vessel arrivals, and port operations would be expected to occur even with the best of preplanning intentions.

- Providing a 1:80,000 scale chart for vessel operations in the immediate vicinity of the port. This chart should be sufficiently inclusive of patterns of rigs and structures which would be expected to be used by VLCC operators piloting in the vicinity of the port.

5.3.3 Degraded Navigation Equipment

The use of precision long-range navigation equipment provides sufficiently accurate positioning information to make the transition from open ocean to coastwise steaming routine and safe. When these systems are not available, as a result of equipment malfunctions, the operator of a vessel transiting toward a port must rely on the short range aids to establish his landfall. Under extreme conditions of currents and poor weather, the possibility exists that discrepancies can occur between a ship's dead reckoning position and its actual location. The potential consequence of this is that the vessel would make a landfall where ambiguous information would lead to unsafe operation of the vessel. The final scenario which was examined involved such a situation. Celestial and long-range navigation had been precluded for over 24 hours. The dead reckoning position indicated that the vessel would arrive in the vicinity of the deepwater port while the actual location of the vessel was several miles to the southwest along a similar RDF bearing. A slow moving ship within radar range was located approximately where two rigs would have been if the ship were at the DR location.

Several clues to the inconsistency of the information were available. Water depth was less than the DR would suggest, and of course the object on the radar display was moving very slowly. A close scrutiny of the Fathometer indication and the radar presentation was required to detect the error in position. Such a scrutiny, it was believed, might only occur if the master was doubtful of his DR.

Each subject was exposed to this scenario only once and only after completing all of the other scenarios. There were 12 transits of this scenario. The analysis of data shows that:

- Ship masters rely on their best previous information when new information is unavailable. They do not maneuver immediately upon discovering that their position may be in error. Rather they attempt to accumulate additional, more reliable information before changing course. The exception to this finding would be in approaching shoal water or specifically identifiable hazards.

- Once masters had determined their actual location, they proceeded on a course toward the safety fairway which would minimize maneuvering at the fairway.

- At no time did any apparent loss of reasoning or logical process, or extreme anxiety occur for any subject. Further, although some subjects acknowledged that they were temporarily "lost" (sic), none considered his situation dangerous or irreconcilable with the information available to him.

- DR position was doubted after one or two attempts to confirm it based on the available information. The time required to question ownship position varied from 5 to 25 minutes.

- Actual position was confirmed with available information at between 30 to 55 minutes into the simulation (an average of 20 minutes after error confirmation).

- Table 25 (lines 4, 14, and 15) indicates significantly greater use of RDF, radar, and Fathometer than the coastwise or landfall approach scenarios. This suggests that during landfall ship operators will rely on the use of long-range aids when they are available but will readily increase their use of short-range aids when long-range information is unavailable.

- Typically, running RDF fixes, line of soundings, and radar pattern interpretation were used to resolve the ambiguity of position and set a course for the deepwater port fairway.

5.3.4 Summary of Navigational Safety Findings

No evidence was revealed which indicates that the transits to a Gulf of Mexico deepwater port contain subtle hazards not previously identified. That is not to say that the scenarios were error free. A number of procedural and shiphandling errors were observed including:

1. A 10-degree error in a course order was given and not detected for nearly half an hour.

2. The motion of a traffic ship was misjudged on one occasion, developing into a long stern chase on a parallel heading.

3. During a presimulation exercise, a slow moving traffic ship was temporarily mistaken for a buoy marking the entrance to the precautionary area.

4. A lower than intended CPA to a passing traffic ship occurred in a safety fairway, due in part to inattentiveness and unfamiliarity with the radar equipment.

After analyzing the causes and severity of these errors, it was concluded that the design of the deepwater port was not a factor in their occurrence.

5.4 CONCLUSIONS ON THE EFFECT OF NAVIGATION DISPLAYS AND BRIDGE PERSONNEL ORGANIZATION IN DEEPWATER PORT APPROACHES

Notwithstanding the results of the safety assessment analysis, there is considerable evidence to indicate that bridge procedures and display enhancements did affect ship transits in the vicinity of the simulated Gulf of Mexico deepwater port. Behavior of ship operators was affected by the form and content of the navigation displays, and there appears to be evidence that the application of organized bridge team procedures resulted in observable performance differences.

5.4.1 The Effect of Display Enhancements

As a subset of the overall safety of navigation questions addressed by this research, the impact of the availability of racons, ARPA, and chart data superimposed on ARPA, on approaches to the deepwater port was observed and evaluated.

Across all scenarios, there was a tendency to direct the vessel's track on a common course when racons were provided.

- During the landfall approach, the tracks when the racons were available showed significantly smaller crosstrack variability when approaching the fairway entrance.

- During the coastwise approach, the addition of racons significantly reduced almost all crosstrack variability.

- When the racons were provided, the operators tended to range or focus on the racon ahead. This display enhancement resulted in consistent and straight tracks to the safety fairway as well as reduced variability.

- Virtually no track variability was observed when the racons were provided in the mooring master approach scenario. Overall, a more common approach was demonstrated with comparable safety and shiphandling performance.

- Racons aided in recognition of position error and in determining actual position during the degraded DR scenario.

The conclusion to be drawn from this evidence is that the racons did modify trackkeeping behavior associated with approaches to an offshore deepwater port. The exact nature of the racon effect and the effect of racon placement was not addressed in the research. In general, however, it appears that racons placed near a destination will tend to focus the tracks of vessels approaching the racon, while racons placed adjacent to the port will direct ships on a course perpendicular to the racon. This pilotage technique, possibly a form of radar parallel indexing, appears to be used even when the formal technique is not familiar to the operator.

There was little evidence that the ARPA display resulted in differences in track, although the masters appreciated the display's ability to differentiate fixed and moving objects.

With the addition of the fairway boundaries superimposed on the ARPA display (ARPA/NAV), the evidence points to a conclusion that the display provided greater freedom of individual preference in the approach.

- With the addition of the navigation option during the landfall scenario, subjects exercised more maneuvering options by selecting a preferred track as the result of increased confidence in their position in the fairway. Some subjects transited down the center of the fairway while others chose to transit to the right of the center.

- In spite of the increased maneuvering which was observed, the subjects with the ARPA/NAV option performed fewer navigation fixes.

- The mooring master area approach scenario provided evidence that masters exercised more individual preference in selecting their tracks using the ARPA/NAV display. The largest crosstrack variability in tracks was observed when the ARPA/NAV display was used. Overall, more individual pilotage preference was demonstrated with comparable safety and shiphandling performance.

5.4.2 Effect of Bridge Personnel Organization

Four of the twelve experimental subjects employed a formal bridge team organization. While the quantitative evidence is not compelling, there is a substantial descriptive evidence that those individuals who used the collaborative techniques performed more consistently and were better able to attain the goals which they had set for themselves.

- In the landfall scenario, while both organizations attempted to enter the north/south safety fairway near the center of the intersection, the team organized crew achieved this goal while the traditionally organized crews tended either to overshoot or cut the corner.

- There is some indication that the traditionally organized crews benefited most from the addition of the racons. The team organized crews were aware of the parallel indexing technique and practiced it regardless of the availability of racons. The traditional crews tended to be more affected by the presence of the racon. They may have relied upon it unintentionally.

- There did appear to be differences in performance as a result of organizational procedures during the coastwise, degraded DR and mooring master approach scenarios. There is evidence that the team organized crews applied certain procedures which enabled them to more effectively conduct each approach.

The overall impression of the researchers was that the team organized crews worked in a collaborative environment, checking information and confirming data. Their plans were at times extremely detailed, particularly during the mooring master approach scenario, yet they maintained the greatest flexibility in response to developing situations. This differed from the traditionally organized crews which at their extreme were one man operations. In at least two instances, the traditionally organized masters dominated the scenarios and made little use of their mates.

5.5 SPECIFIC RECOMMENDATIONS

The research approach employed concentrated attention on issues of practical interest to the U. S. Coast Guard, deepwater port operators, and shipping companies. Conclusions and recommendations related to vessel operations in the vicinity of a deepwater port in the Gulf of Mexico follow directly from the research process. These conclusions and recommendations are presented in the following categories:

1. Offshore deepwater port operational guidelines.
2. Short-range aids to navigation.
3. Long-range aids to navigation and traffic management.
4. Training and procedures.
5. Bridge equipment/displays.

In addition to conclusions and recommendations which apply directly to Gulf of Mexico deepwater ports, some findings can be generalized to near inshore ports or offshore ports in other areas. In instances where this supplemental application is appropriate, the findings are stated and qualified to reflect a judicious balance between maximum use of the findings and prudent caution to avoid overgeneralization.

5.5.1 Offshore Deepwater Port Operational Guidelines

Recommendation

On the basis of descriptive experimental evidence which showed varied performance among masters as they maneuvered a loaded VLCC at low speed through the dogleg in the LOOP safety fairway, we recommend that LOOP consider one or both of the following:

1. Removal or reduction of the dogleg to produce a straight-in approach to the precautionary area.

2. Relocation of the mooring master pickup point further south in the safety fairway such that the turn maneuver can be made at maneuvering speed rather than at speed where control is marginal.

We believe that the following issues need to be addressed in consideration of this recommendation:

1. Lease block considerations may affect recommendation 1.

2. Other traffic within the vicinity may encumber the maneuver.

3. Mooring master delays may require additional maneuvering at low speed in an area where the master's options are restricted.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we believe that whenever possible, approaches should be designed to minimize requirements for turn maneuvering at areas in which low speed, traffic, environment or operational uncertainties are present. In effect, when nearing the pick-up point, the master should have a minimum of maneuvering requirements other than those which ensure the safe and expedient reception of the mooring master.

Recommendation

On the basis of conclusions that (1) mooring master delays will occur, (2) vessels could encounter circumstances which would make circling or drifting impractical and (3) some masters may feel the need to anchor either in the safety fairway or elsewhere rather than return to sea; we recommend that LOOP provide a holding anchorage for use by ships' masters.

We believe that the following issues need to be addressed in consideration of this recommendation:

1. That the anchorage be sufficiently near the mooring master pickup point so that (a) it may be used conveniently in the event the mooring master is delayed and (b) the mooring master need not travel far to board a ship in the anchorage.

2. That the anchorage be of sufficient depth for the vessels' drafts yet adequate to accommodate the scope of anchor chain available aboard a VLCC.

3. That the anchorage be adequately marked and identified for all weather operations.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we believe that whenever possible an anchorage, which does not interfere with port operations, should be provided for use by ship masters.

Recommendation

On the basis of observation that the existing chart of the LOOP area, i.e., Barataria Bay and Approaches (NOAA 11358) are of insufficient scale and/or improper coordinates for use in LOOP approach pilotage, we recommend that NOAA consider the publication of a 1:80,000 scale chart centered on 28 degrees 45 minutes north latitude and 90 degrees west longitude. The chart should include, but not be limited to, delineations of the safety fairway, anchorage, and precautionary area. Each special area should be clearly labeled to convey its use and limitations. The chart should show all offshore structures at least within 12 miles of the safety fairway as well as pipelines, obstructions and other possible hazards to navigation which are outside the safety fairways.

We believe that the following issue needs to be addressed in consideration of the recommendation:

1. A chart has been designed and is planned for implementation in LOOP. It does not, however, meet the above recommendations. Revision to the design should be considered to make the chart reflect the location of all area boundaries and allow sufficient detail for piloting in the vicinity of LOOP.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we recommend that safety fairway dimensions, density of surrounding structures and availability of aids to navigation all be considered in the selection of scale and geographic coordinates for port specific charts.

5.5.2 Short-Range Aids to Navigation

Recommendation

On the basis of inferential and descriptive experimental evidence which showed unique approach behavior to the deepwater port when racons were used, we recommend that the U. S. Coast Guard consider any or all of the following:

1. Controlled investigation of why racons tended to align all masters' tracks and either focus them toward the racon or parallel them adjacent to the racon.

2. Investigation of racons as a mechanism for aiding the transition from open-sea navigation to the approach phase.

3. Investigation of other racon placements and racon navigating techniques to produce desirable piloting characteristics in approach to a deepwater port.

We further recommend that LOOP and the Coast Guard consider any or all of the following:

1. Location of an additional racon or racons south of the pumping complex for the purpose of (a) providing a leading mark for vessels transiting outside the safety fairway from Southwest Pass, (b) provide a leading mark for vessels entering the north/south safety fairway at its entrance and (c) provide positive identification of the LOOP area in the event of failure of long-range aids to navigation during the approach.

2. Placement of racons as a position reference for communications, ship maneuvering, traffic identification and control.

3. The use of racons to make the area more recognizable to masters.

Based upon the use of racons and their subsequent effect on pilotage performance which was demonstrated in the study, we recommend the installation of racons at the following locations within the LOOP area:

1. The platform structure located at approximately 28 degrees 32.8 minutes north latitude and 90 degrees 4.1 minutes west longitude.

2. The platform structure located at approximately 28 degrees 35.3 minutes north latitude and 89 degrees 42.0 minutes west longitude.

According to the study findings, racons located at these positions (1) will facilitate the transition from open-sea navigation to the landfall phase of the approach, (2) will enable masters to parallel or range on the racons using standard piloting techniques, and (3) will provide a demarcation for identifying the southernmost part of the existing rig field.

We believe that the following issues need to be addressed in consideration of this recommendation:

1. Uncertainty of the causes for trackkeeping behavior which resulted from the placement of a single racon or group of racons.

2. The effects of using racons in conjunction with other aids to navigation.

3. The use of racons with specific piloting techniques such as bow and beam method, danger bearing method, and parallel index plotting.

4. The use of racon applications and techniques not addressed in this study, but which could be of more benefit in port specific approaches.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we believe this study has shown that wider use of racons would serve a significant benefit to the safety and efficiency of the overall port operation. The extent and nature of the racon application, however, will be dependent upon resolution of the effectiveness of racon systems, and the specific design requirements of the particular port.

5.5.3 Long-Range Aids to Navigation and Traffic Management

Recommendation

On the basis of the chain of experimental evidence which showed no detriment to safety or prudent navigating practice as a result of removing the primary long-range aid to navigation (in this case loran-C), we recommend that alternative radio aids to navigation systems be maintained at all times even in areas in which rig patterns are visible on the radar. Further, it is recommended that while RDF is adequate as a backup long-range aid to navigation system, a hyperbolic line or satellite system is essential to ensure optimum transition from open sea to the approach phase of a deepwater port operation.

We believe that the following issues need to be addressed in consideration of this recommendation:

1. The actual accuracy and operational effectiveness of long-range aids to navigation systems in the LOOP area.

2. Minimum equipment requirements of vessels employed in the LOOP operation and the ability of LOOP or regulatory organizations to impact this requirement.

3. The need for additional controlled experimentation on the effect of or absence of various long-range aids to navigation systems during specific contingencies within the LOOP operating area.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we conclude the effects will be similar to those demonstrated in the LOOP simulation. That is, while the use of radar piloting and RDF alone can support a safe approach to the safety fairway, multiple long-range aids will significantly expedite the transit and offer an additional margin of safety.

Recommendation

On the basis of the chain of experimental evidence which showed masters entering and transiting the safety fairways either on the right side or in the center as they individually intended, it is concluded that the LOOP safety fairway is of adequate width and its navigation aids are of adequate quality to promote safe traffic separation. Further, simulated encounters with traffic at safety fairway junctions and within safety fairways distant from the LOOP complex revealed safe CPAs for all passings. The absence of simulated passing encounters in the north/south safety fairway, however, renders this experiment insufficient for judging the requirements of a traffic separation scheme. We recommend that additional experimentation be conducted in which both traffic encounters and the LOOP proposed advisory system is simulated. Such an investigation would reveal potential difficulties in traffic control as well as limitations imposed by the physical waterway and VLCC maneuvering characteristics.

We believe that the following issues need to be addressed in consideration of this recommendation:

1. A definition of all operating aspects of the proposed LOOP advisory service.

2. A definition of the minimum equipment requirements for ships operating within the LOOP area. The study findings showed a high degree of pilotage proficiency within the safety fairways when ARPA with a navigation option was used. Such equipment, however, would not likely be installed aboard all VLCCs entering LOOP. The degree of sophistication of equipment which will be installed must be identified.

3. If voluntary traffic separation for the transit of safety fairways appears inadequate, methods other than formal traffic separation schemes could be employed such as a LOOP directive to remain along the right side of the fairway at all times.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we recommend each port design be addressed individually taking into consideration the physical parameters of the waterway, type of traffic encountered, peripheral and environmental factors, and the results of the research which is recommended.

Recommendation

On the basis of observed evidence and discussions with masters, the more traffic and operating information which can be provided within the vicinity of LOOP the better a master's opportunity for achieving prudent and safe pilotage. This is evidenced in the study findings which conclude that while a majority of masters will enter and operate within the safety fairways, some will choose to transit outside the fairways and among the rig structures. As a result, we recommend that a mandatory traffic reporting and advisory scheme be implemented for all vessels approaching LOOP with the scope and detailed procedures to be determined.

We believe that the following issues need to be addressed in consideration of this recommendation:

1. The anticipated frequency and density of LOOP traffic.

2. The efficiency and reliability of the mooring master operation.

3. Ability of ship masters to accurately determine their position within the fairway, estimate their progress and communicate it to the LOOP facility; ability of LOOP to monitor these.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we believe the need for a vessel traffic advisory will be uniquely dependent upon the physical arrangement of each port, the type and amount of traffic anticipated, and the requirements of the mooring or berthing operation involved.

5.5.4 Training and Procedures

Recommendation

On the basis of the chain of experimental evidence which showed only minor performance differences between formally organized bridge teams and traditional bridge crews, we conclude that LOOP approaches will be conducted with comparable effectiveness and safety by either personnel organization. Based upon those differences in performance which did occur, however, we recommend that the shipping companies operating in the LOOP area encourage the use of those methods characteristically employed by team trained and organized crews. These methods are as follows:

1. Preplanning of the approach.

2. Assignment of individual duties to bridge personnel.

3. Review of contingency actions and alternatives.

4. Implementation of cross-checking procedures.

5. Maximized effectiveness of communications.

6. Encouragement of a collaborative spirit.

We believe that the following issue needs to be addressed in consideration of this recommendation:

1. Further investigation into the effects of bridge organization, training, port familiarity, and bridge equipment operating experience on deepwater port approaches.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we believe this study has not provided sufficient data to conclude the effects of personnel organization or procedures for generalized port approaches.

5.5.5 Bridge Equipment/Displays

Recommendation

On the basis of inferential and descriptive experimental evidence which showed unique approach behavior to the deepwater port when different displays were used, we recommend that shipping companies encourage the use of (1) radar for the earliest possible confirmation of position from rig patterns and aids to navigation, (2) racons for enhanced approach navigation and traffic advisory communications, (3) ARPA for improved traffic assessment and rig pattern identification, and (4) ARPA with the navigation option to augment both navigation and collision avoidance.

Further, based upon study conclusions (1) that ARPA with the navigation display increased maneuvering options and subsequently produced a greater diversity of ship tracks, and (2) that racons tended to homogenize all maneuvering and subsequently produced a relatively common track; we believe the following issue needs to be addressed:

1. From a safety, operational effectiveness and traffic control standpoint, determine the desirability of all masters achieving a common ship track versus exercising their preference for different ship tracks.

In considering such action with respect to ports other than the Gulf of Mexico's deepwater ports, we believe the effects on pilotage of ARPA and racons which were revealed in this study will have direct and immediate impact on approach performance to all ports. The effects, however, would be expected to vary as a function of equipment use, personnel training, racon placement and port design; and consequently should not be generalized without additional consideration.

Appendix A

STATISTICAL COMPARISON IN CROSSTRACK VARIABILITY

The figures presented in Appendix A were derived as a result of statistically comparing, using the F-statistic at the $p \leq 0.10$ level of significance, one standard deviation of crosstrack variability between conditions at preselected intervals (0.5 nautical mile or 0.25 nautical mile) along the tracklines. These figures illustrate the difference in variability which existed along the tracklines for each condition, and where it occurred. The data are used as statistical support for conclusions about the group mean track and crosstrack variability plots discussed in Section 4. Only tracklines which revealed a statistically significant difference are presented.

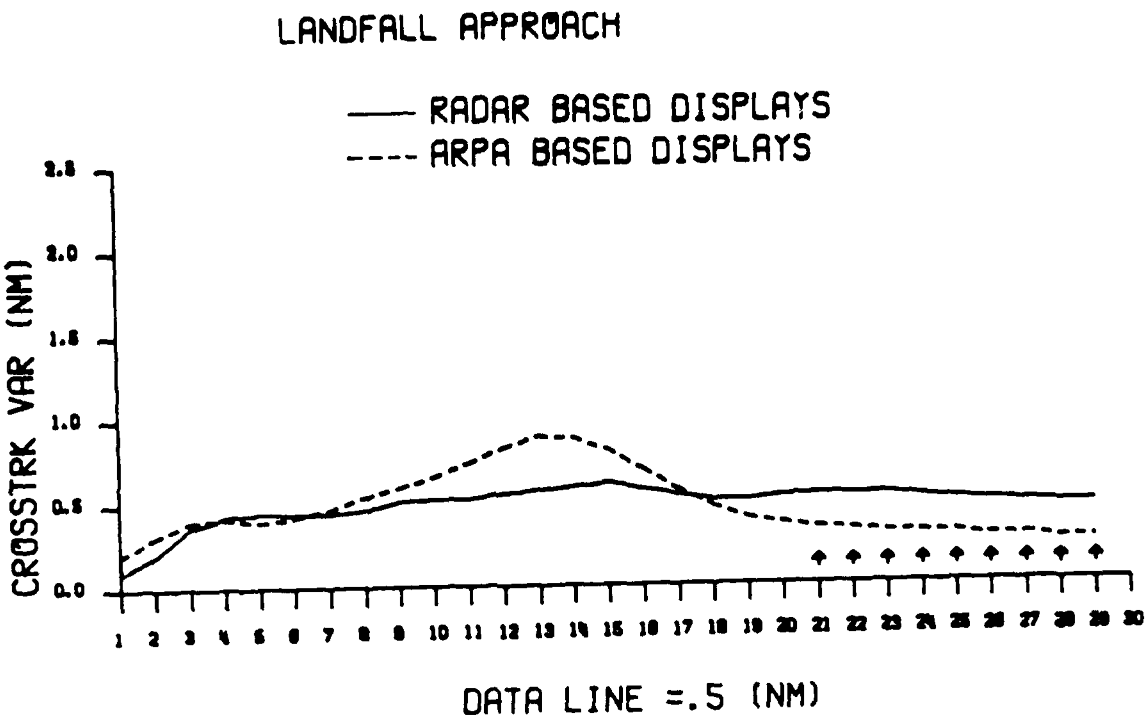
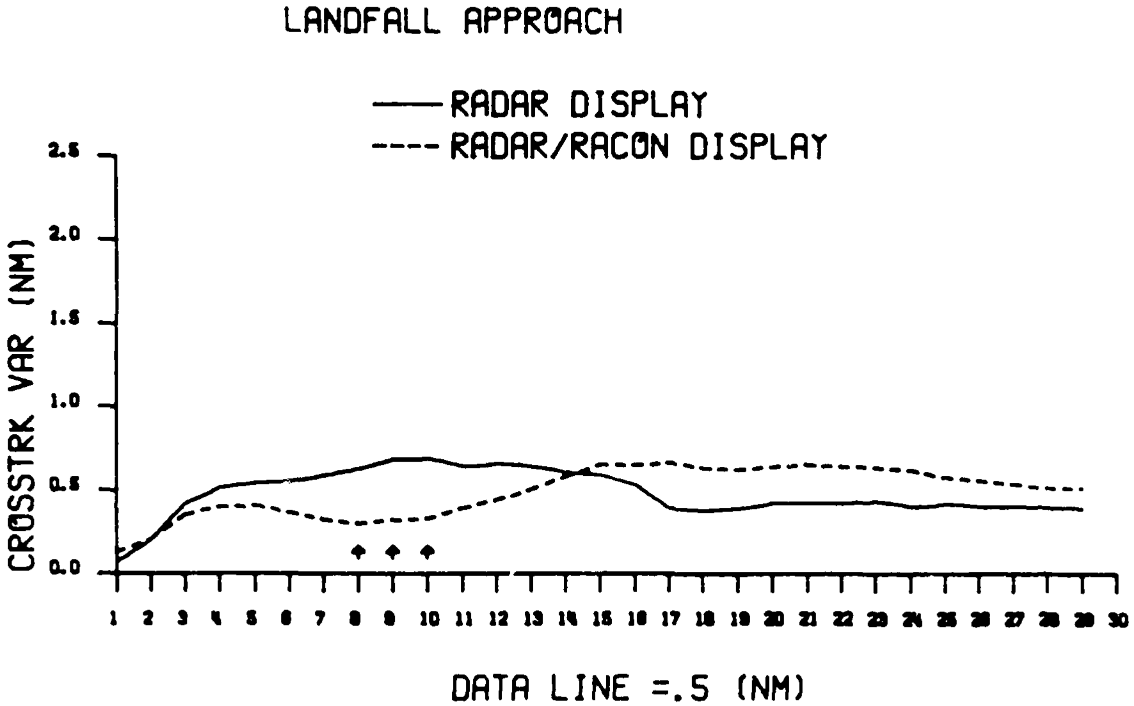
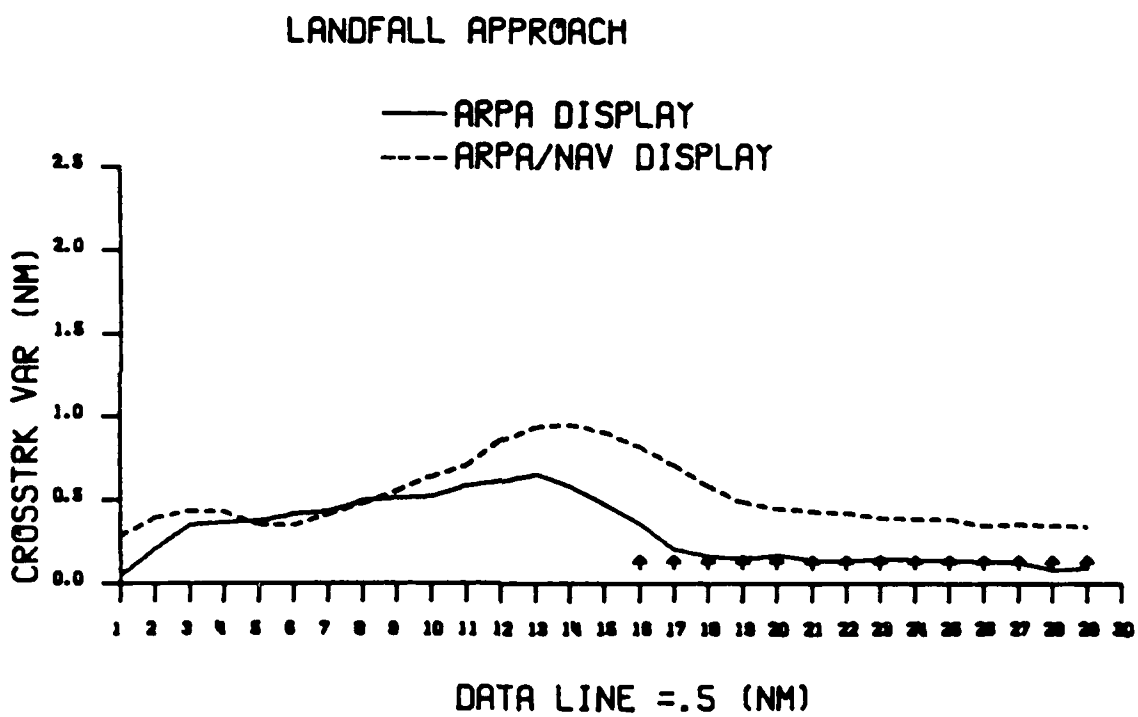

LANDFALL APPROACH
RADAR BASED DISPLAYS
ARPA BASED DISPLAYS
CROSSTRK VAR (NM)
DATA LINE =.5 (NM)

FIGURE A-1



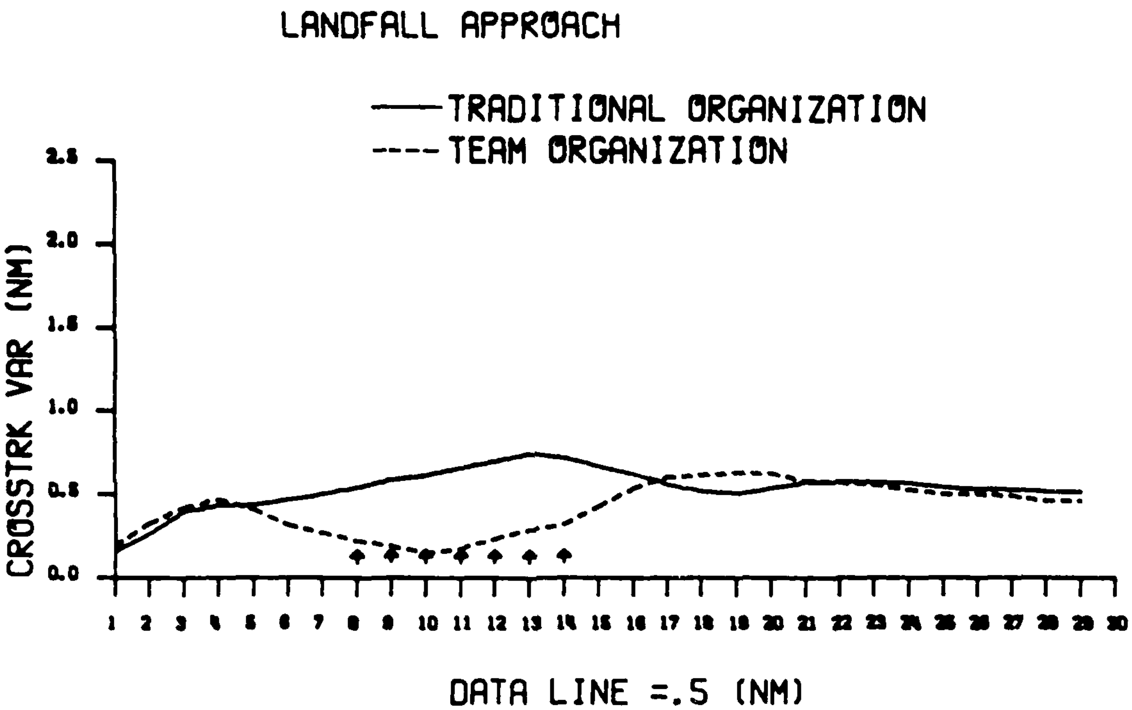
† - STATISTICALLY DIFFERENT AT $p \leq 0.10$ LEVEL OF SIGNIFICANCE

FIGURE A-2



† = STATISTICALLY DIFFERENT AT $p \leq 0.10$ LEVEL OF SIGNIFICANCE

FIGURE A-3



† = STATISTICALLY DIFFERENT AT $p \leq 0.10$ LEVEL OF SIGNIFICANCE

FIGURE A-4

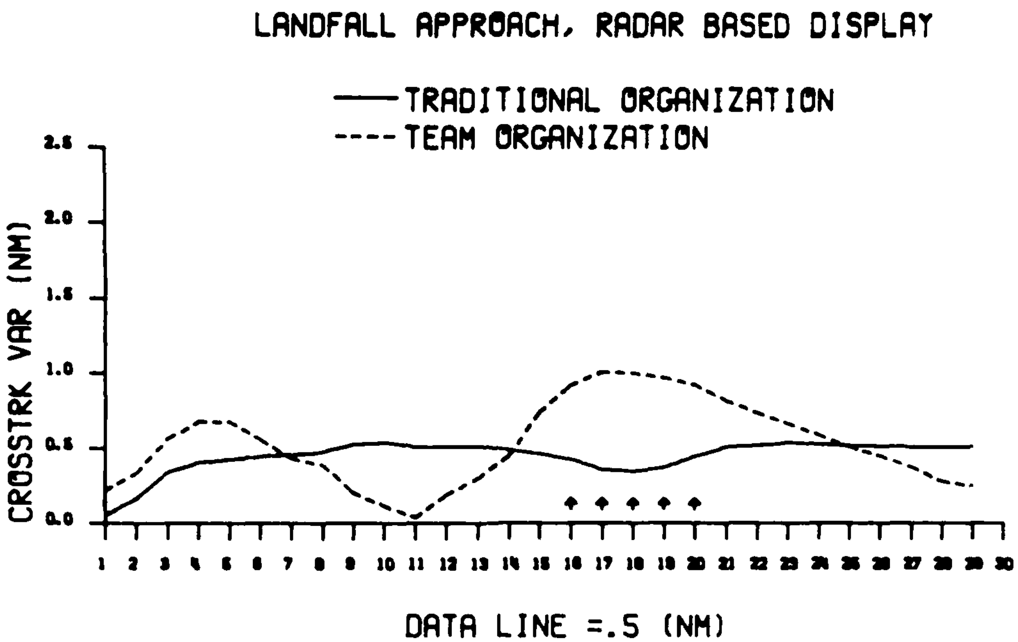

LANDFALL APPROACH, RADAR BASED DISPLAY
TRADITIONAL ORGANIZATION
TEAM ORGANIZATION
CROSSTRK VAR (NM)
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DATA LINE =.5 (NM)

FIGURE A-5

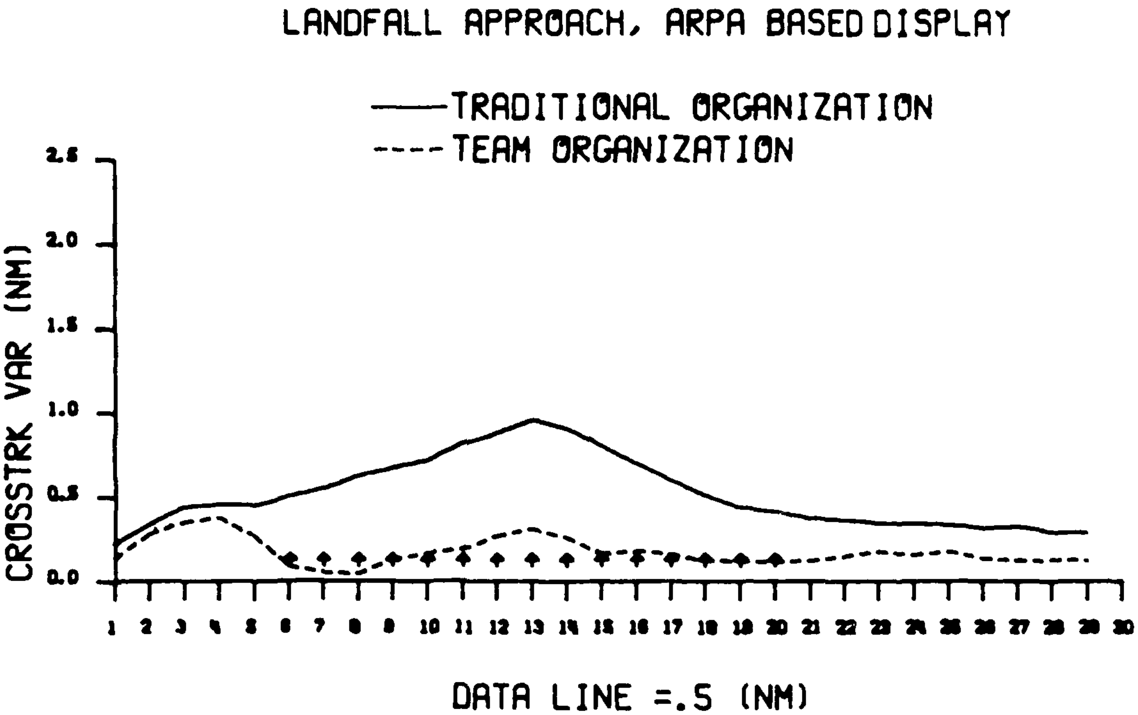

LANDFALL APPROACH, ARPA BASED DISPLAY
TRADITIONAL ORGANIZATION
TEAM ORGANIZATION
CROSSTRK VAR (NM)
DATA LINE =.5 (NM)

FIGURE A-6

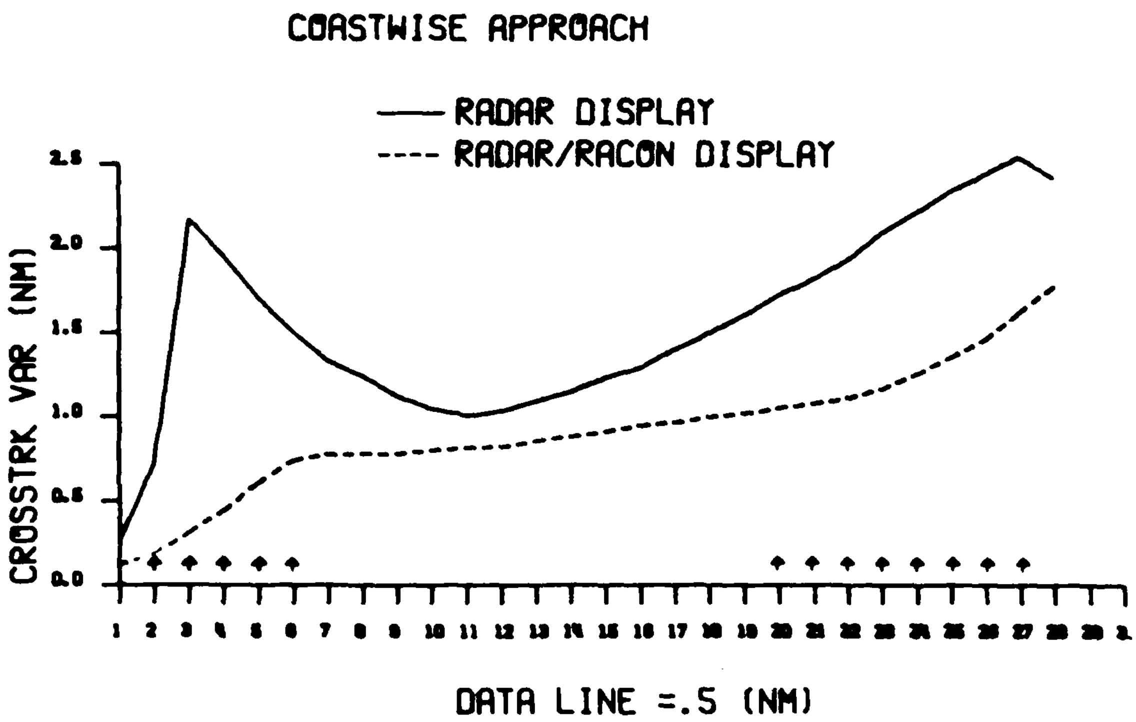
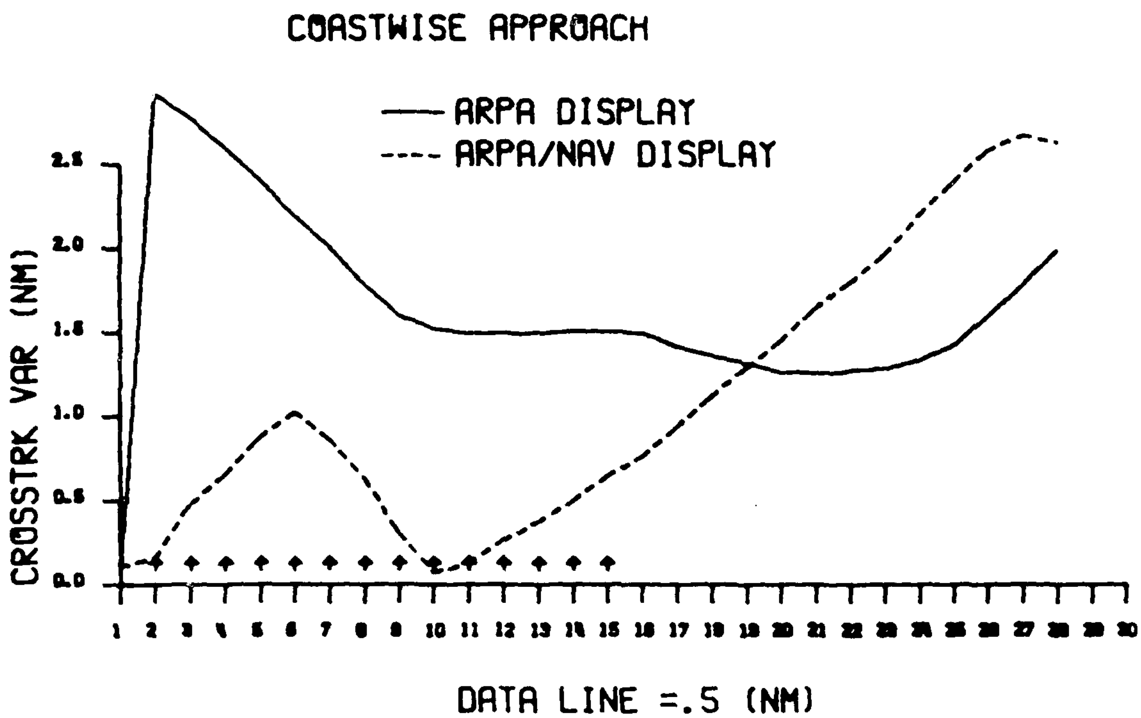
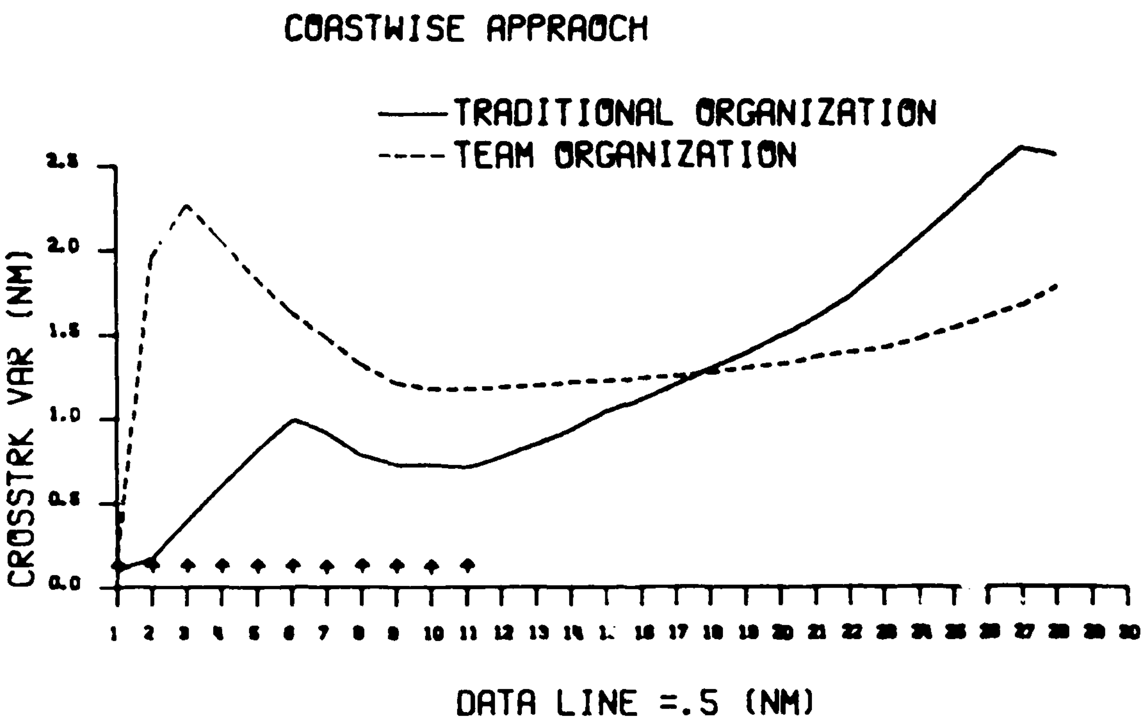

COASTWISE APPROACH
RADAR DISPLAY
RADAR/RACON DISPLAY
CROSSTRK VAR (NM)
2.5
2.0
1.5
1.0
0.5
0.0
DATA LINE =.5 (NM)

FIGURE A-7



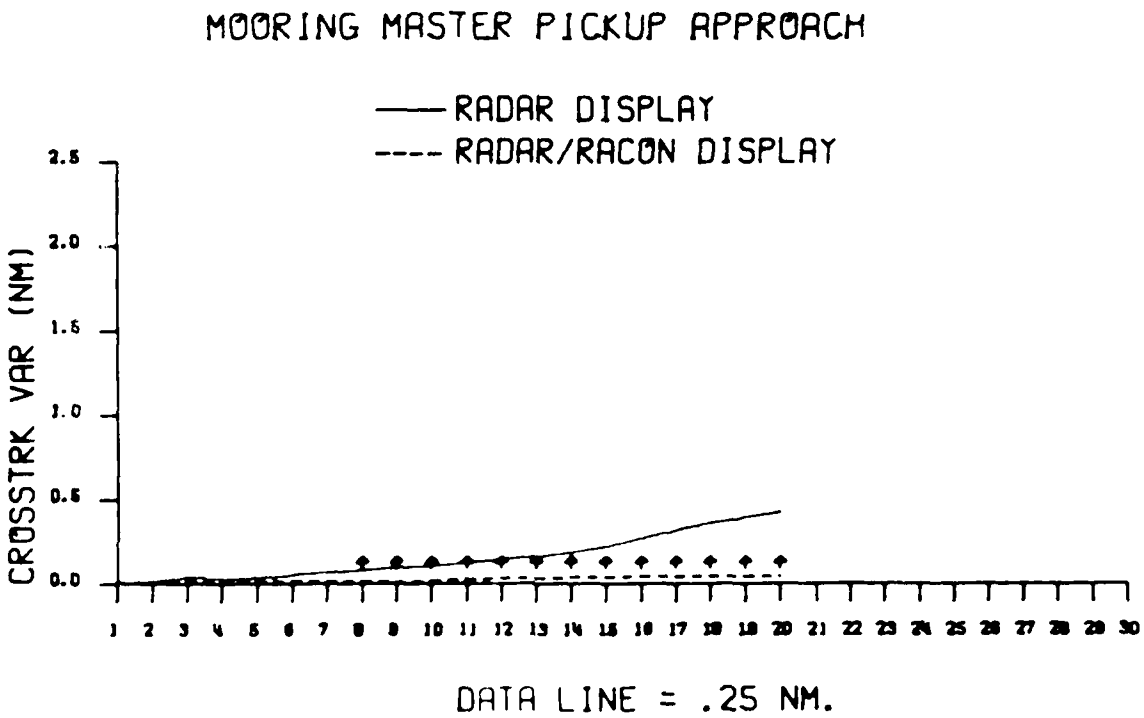
COASTWISE APPROACH
ARPA DISPLAY
ARPA/NAV DISPLAY
CROSSTRK VAR (NM)
2.0
1.0
0.0
DATA LINE =.5 (NM)

FIGURE A-8



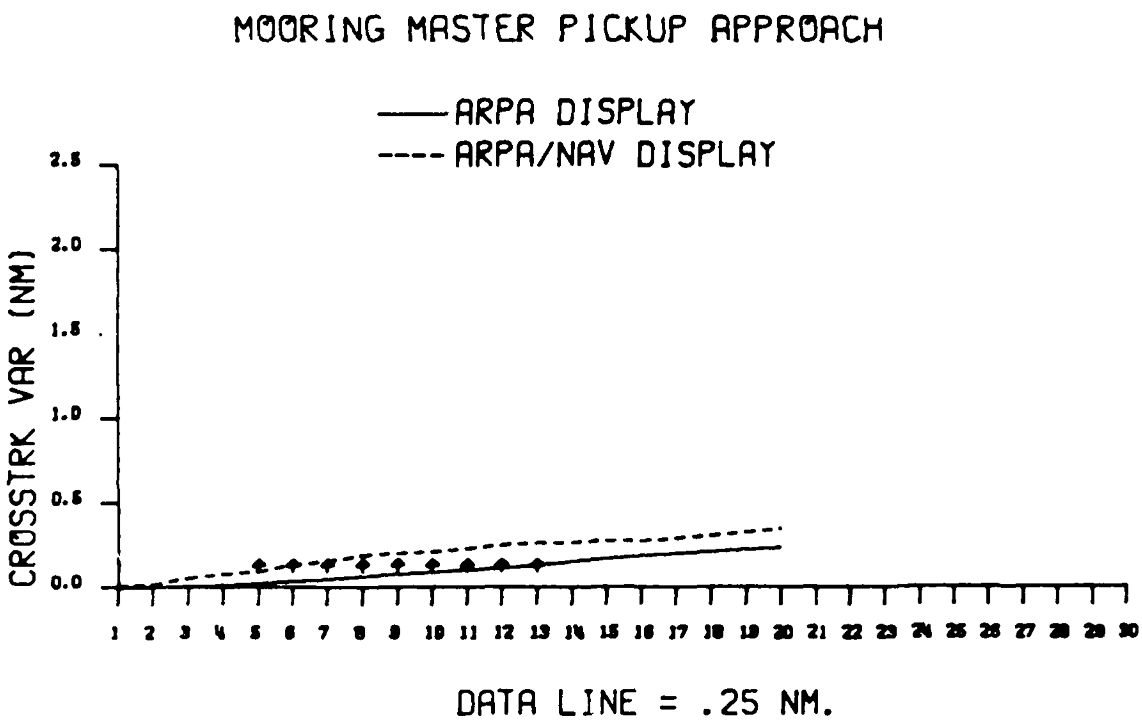
✦ - STATISTICALLY DIFFERENT AT $p \leq 0.10$ LEVEL OF SIGNIFICANCE

FIGURE A-9



* STATISTICALLY DIFFERENT AT α = 0.10 LEVEL OF SIGNIFICANCE

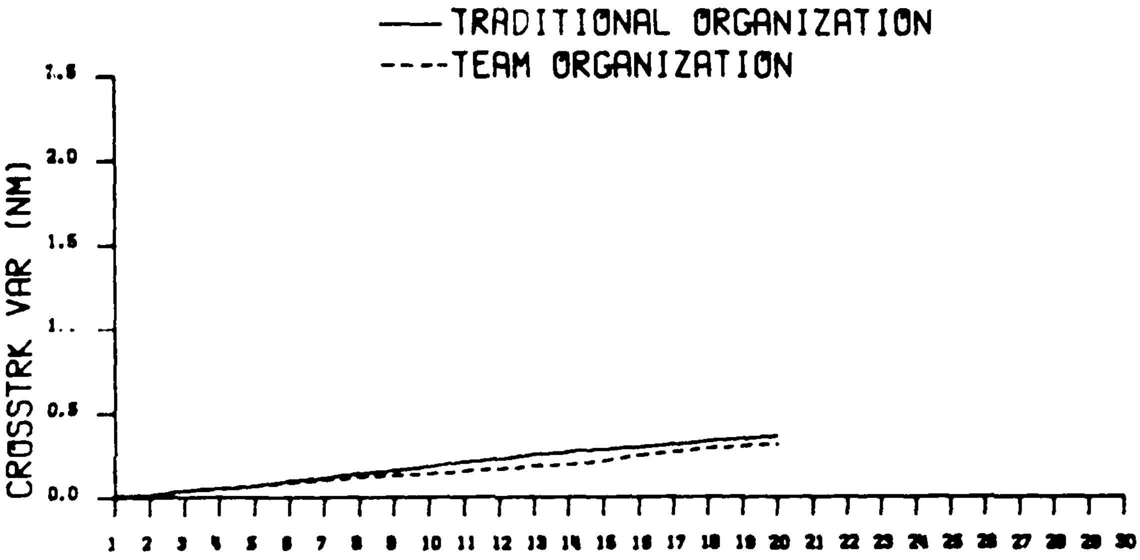
FIGURE A-10



† = STATISTICALLY DIFFERENT AT $p \leq 0.10$ LEVEL OF SIGNIFICANCE

FIGURE A-11

MOORING MASTER PICKUP APPROACH ARPA & ARPA/NAV



DATA LINE = .25 NM.

† = STATISTICALLY DIFFERENT AT p < 0.10 LEVEL OF SIGNIFICANCE

FIGURE A-12

Appendix B

TRACK PLOTS BY CONDITION SHOWING MEAN TRACK AND PLUS OR MINUS TWO STANDARD DEVIATION CROSSTRACK VARIABILITY

The figures presented in Appendix B show differences in group mean track and plus or minus two standard deviation crosstrack variability for each display enhancement and bridge organization conditions analyzed in Section 4.

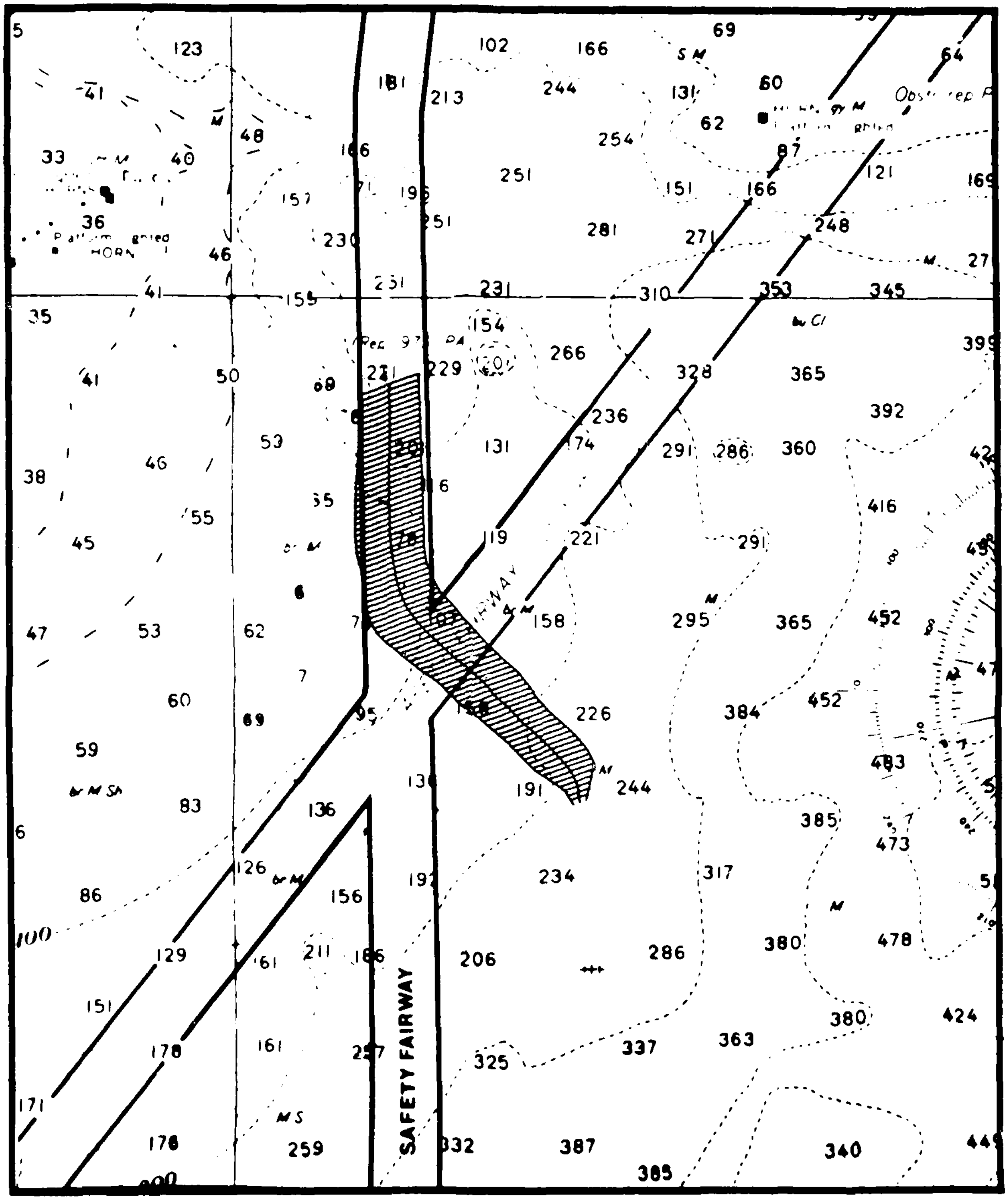


FIGURE B-1. RADAR BASED DISPLAYS – LANDFALL APPROACH

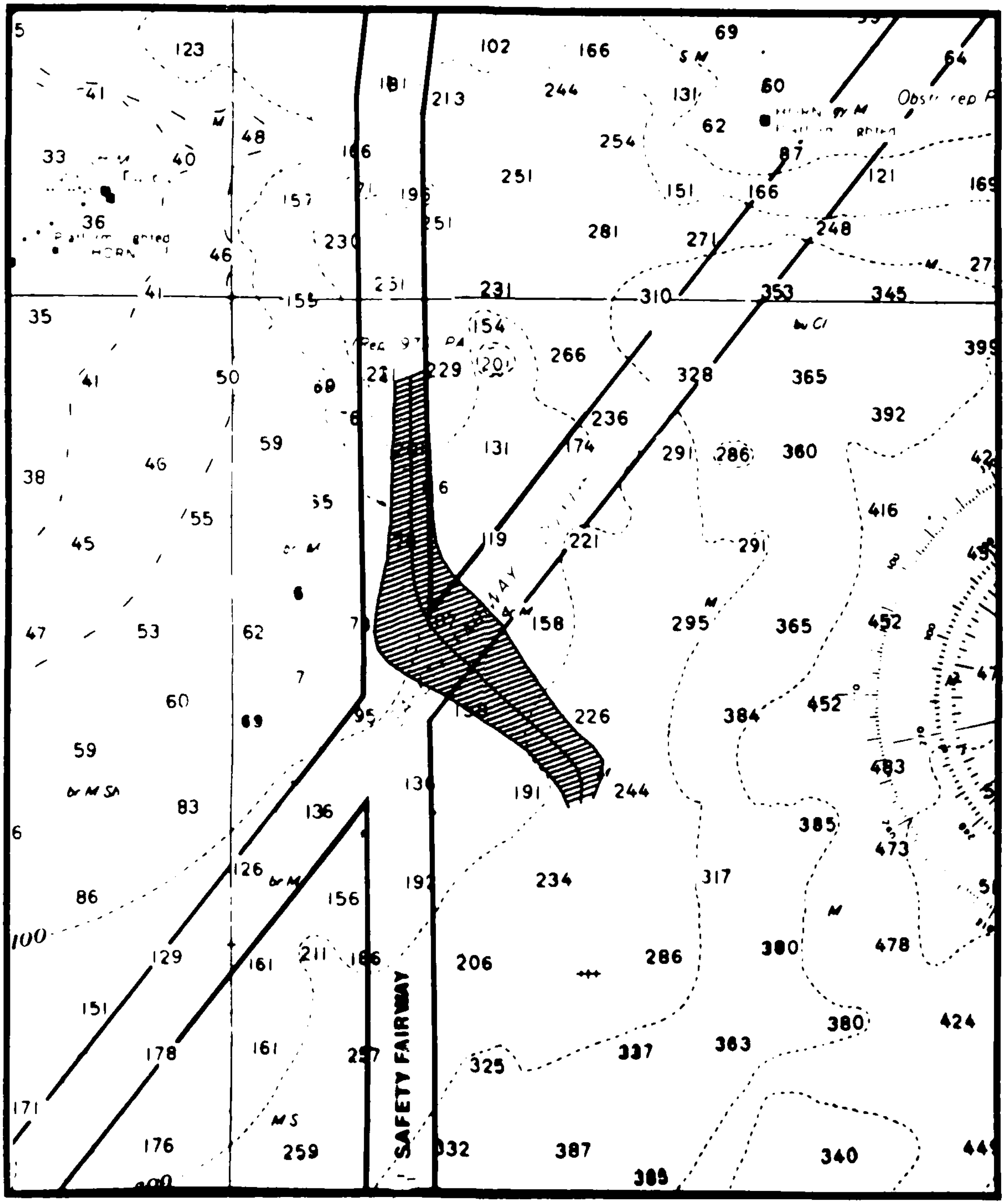


FIGURE B-2. ARPA BASED DISPLAYS – LANDFALL APPROACH

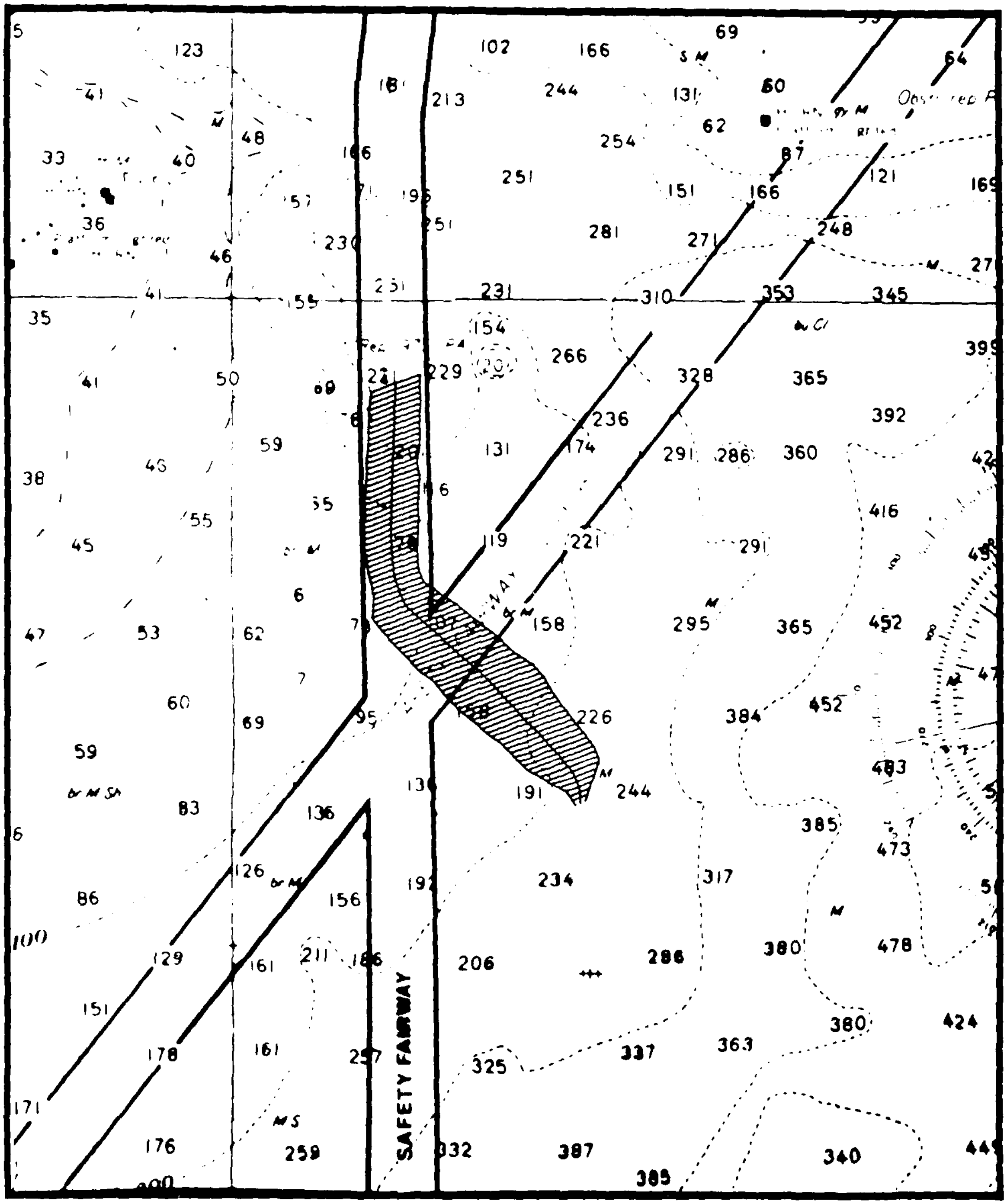


FIGURE B-3. RADAR – LANDFALL APPROACH

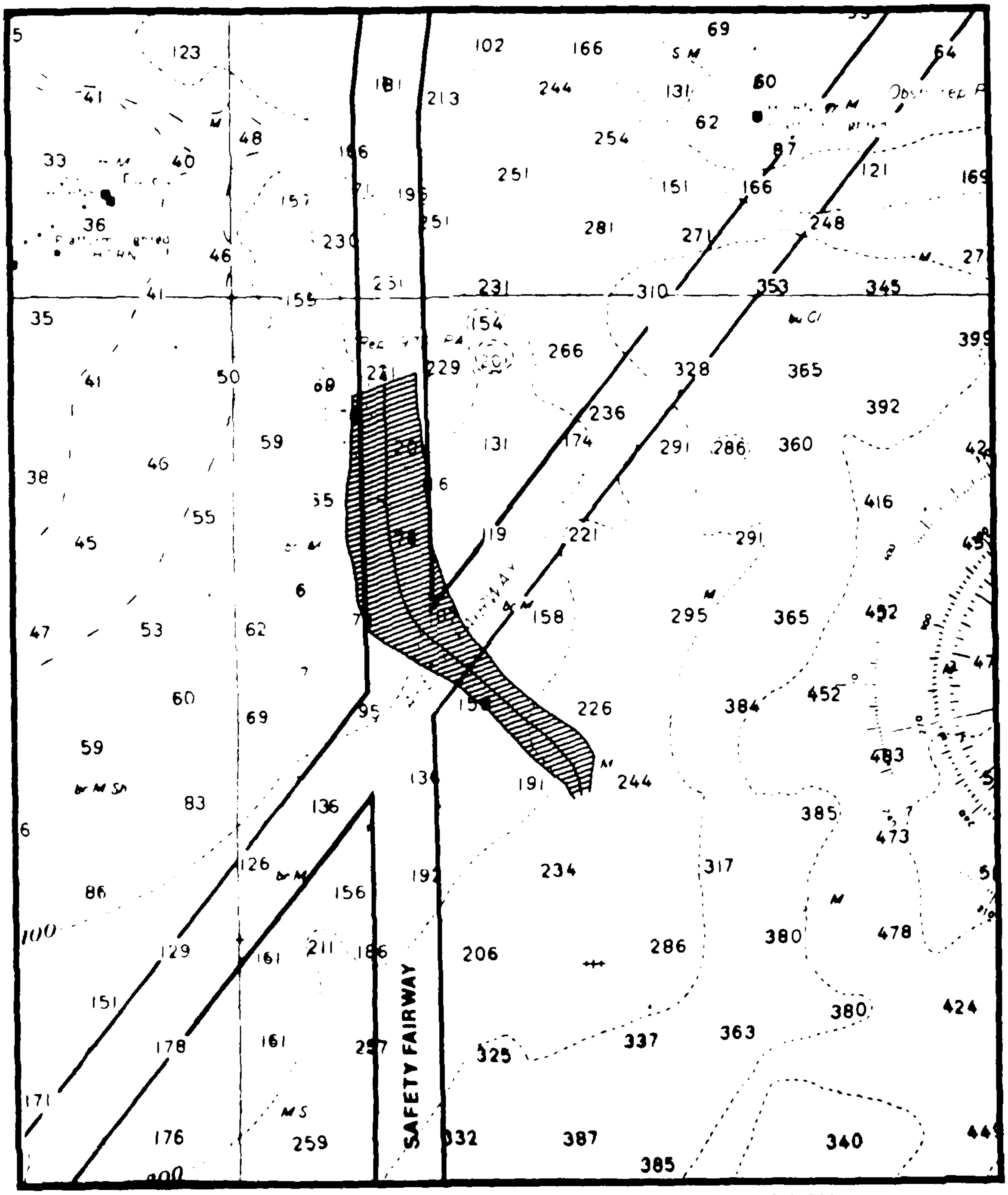


FIGURE B-4. RADAR/RACON – LANDFALL APPROACH

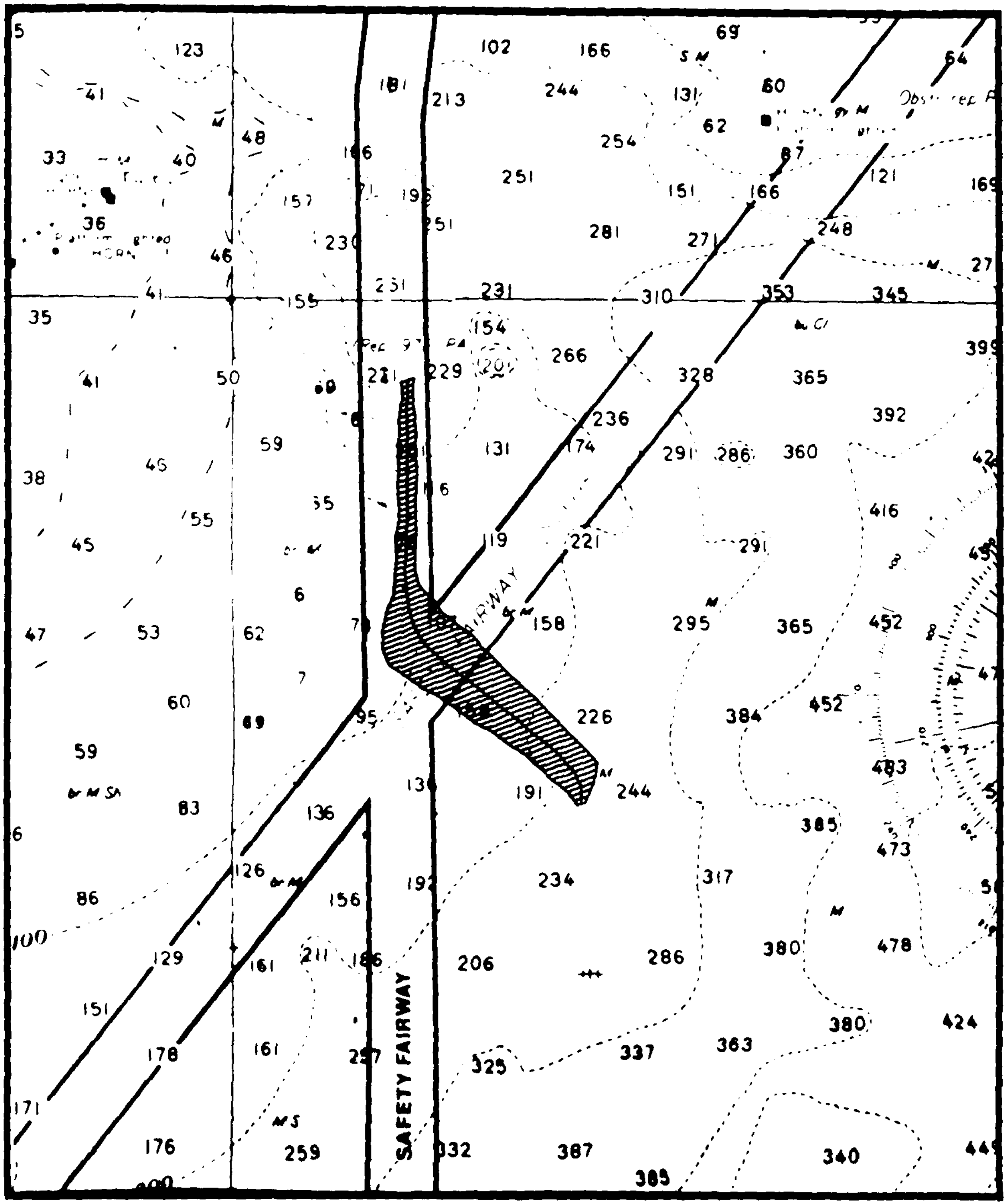


FIGURE B-5. ARPA – LANDFALL APPROACH

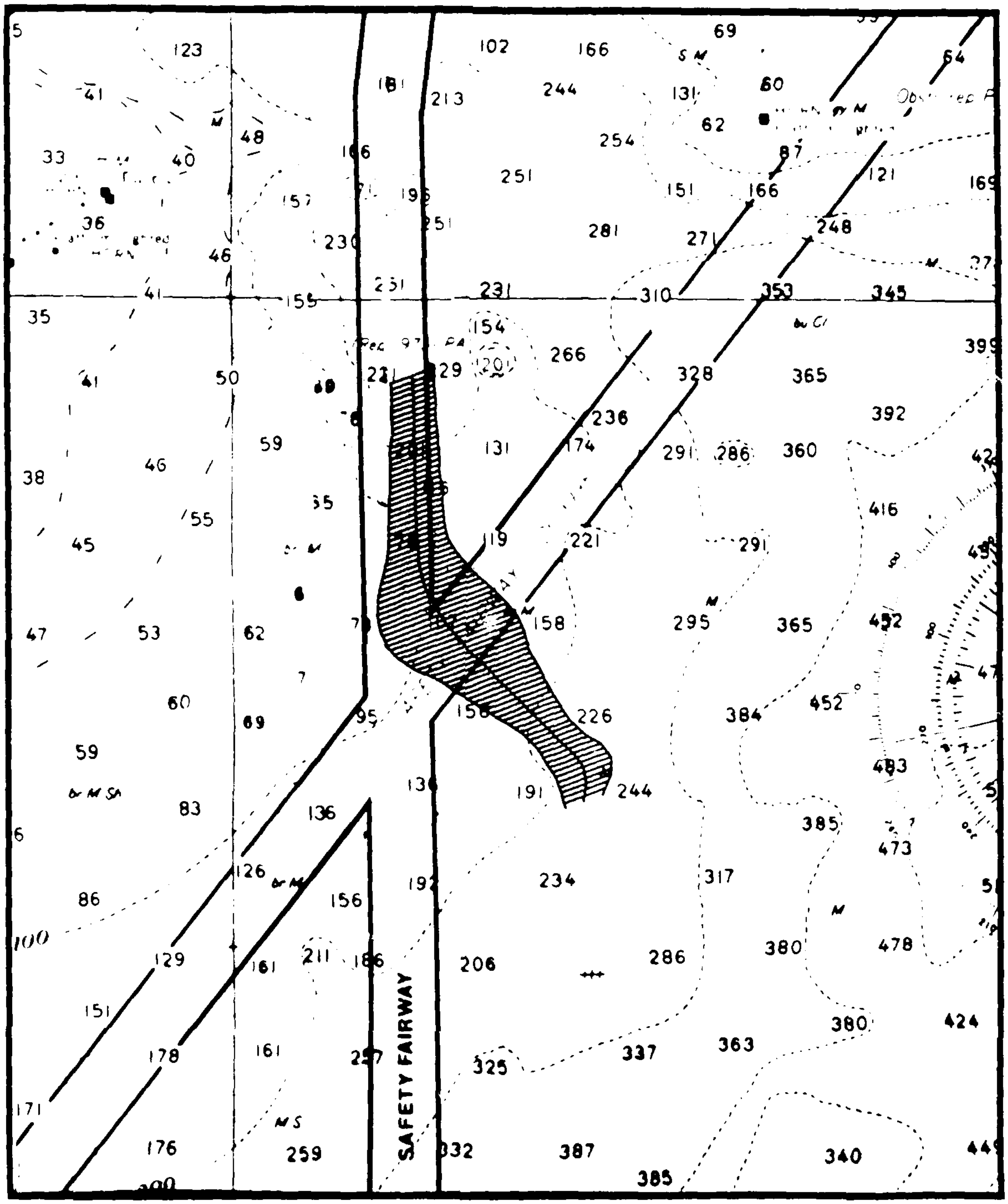


FIGURE B-6. ARPA/NAV – LANDFALL APPROACH

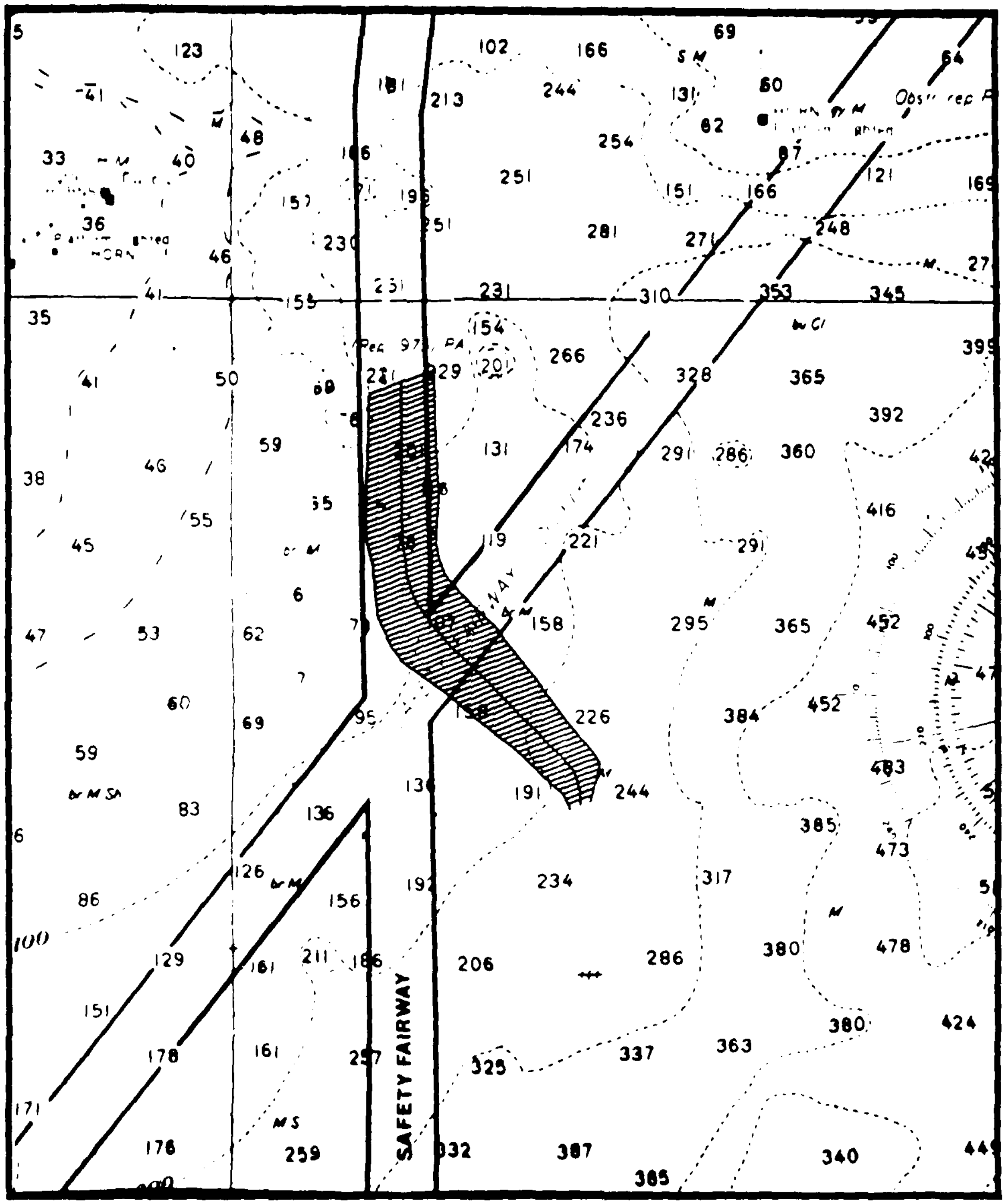


FIGURE B-7. TRADITIONAL ORGANIZATION – LANDFALL APPROACH

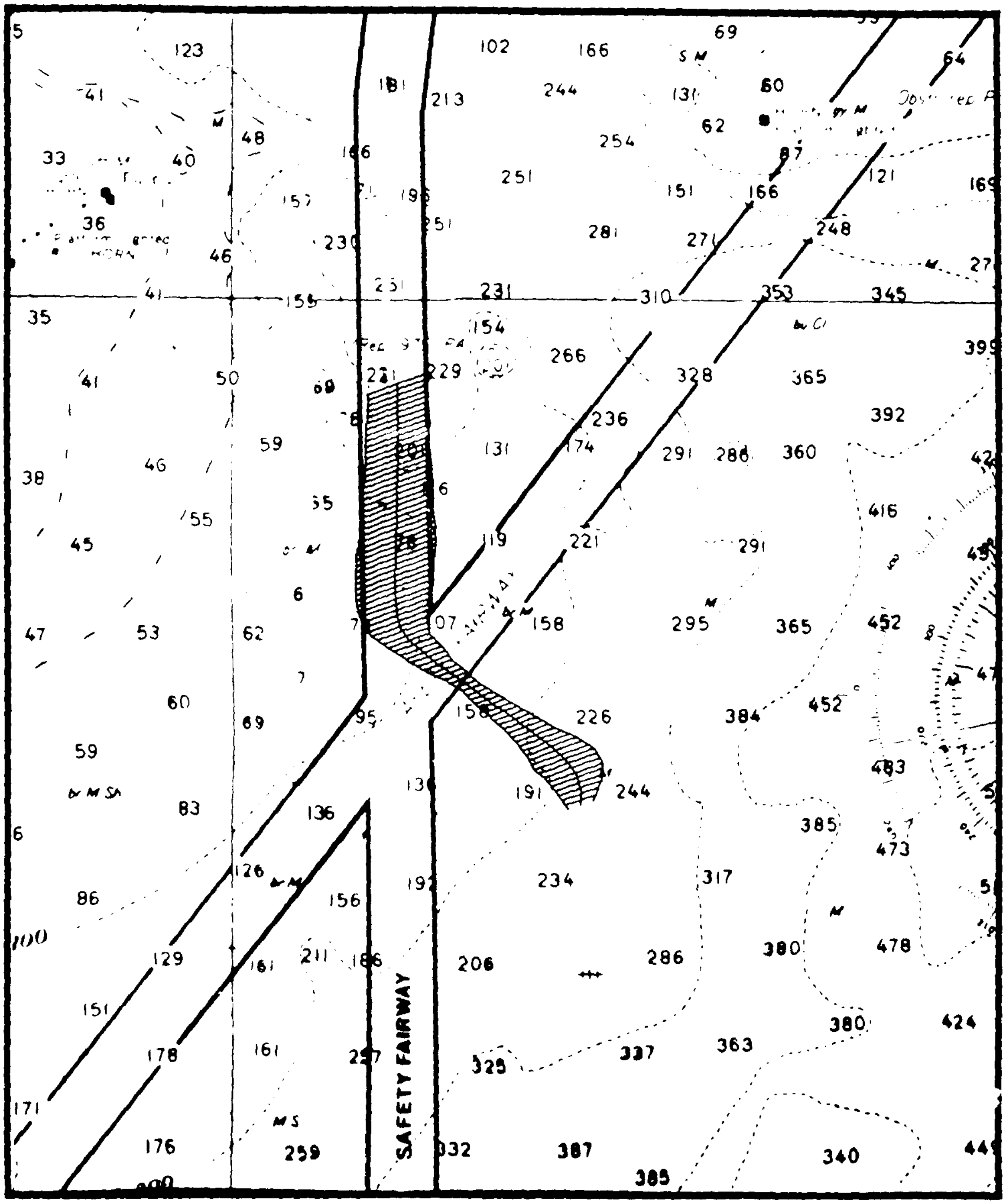


FIGURE B-8. TEAM ORGANIZATION – LANDFALL APPROACH

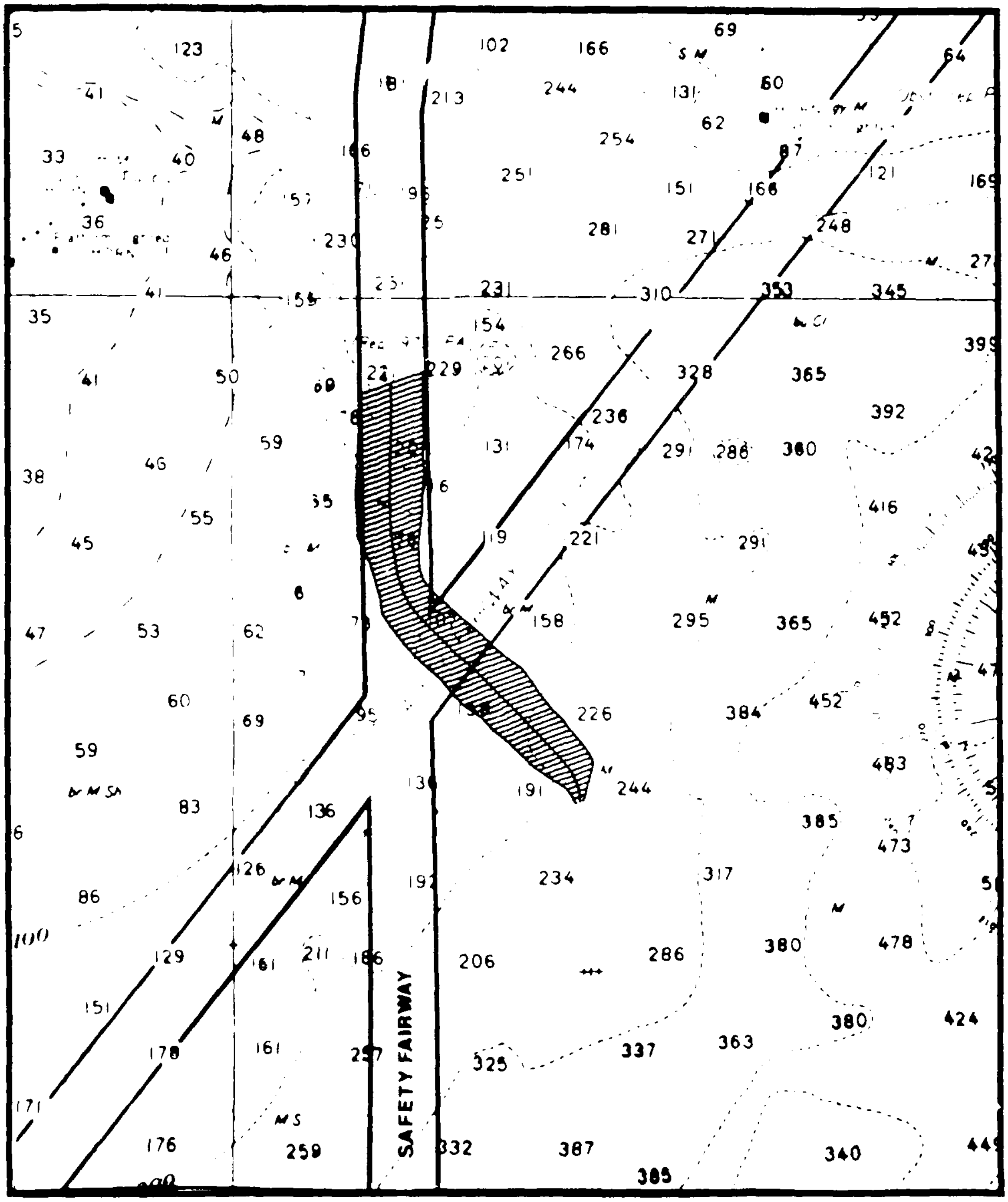


FIGURE B-9. RADAR BASED DISPLAYS, TRADITIONAL ORGANIZATION – LANDFALL APPROACH

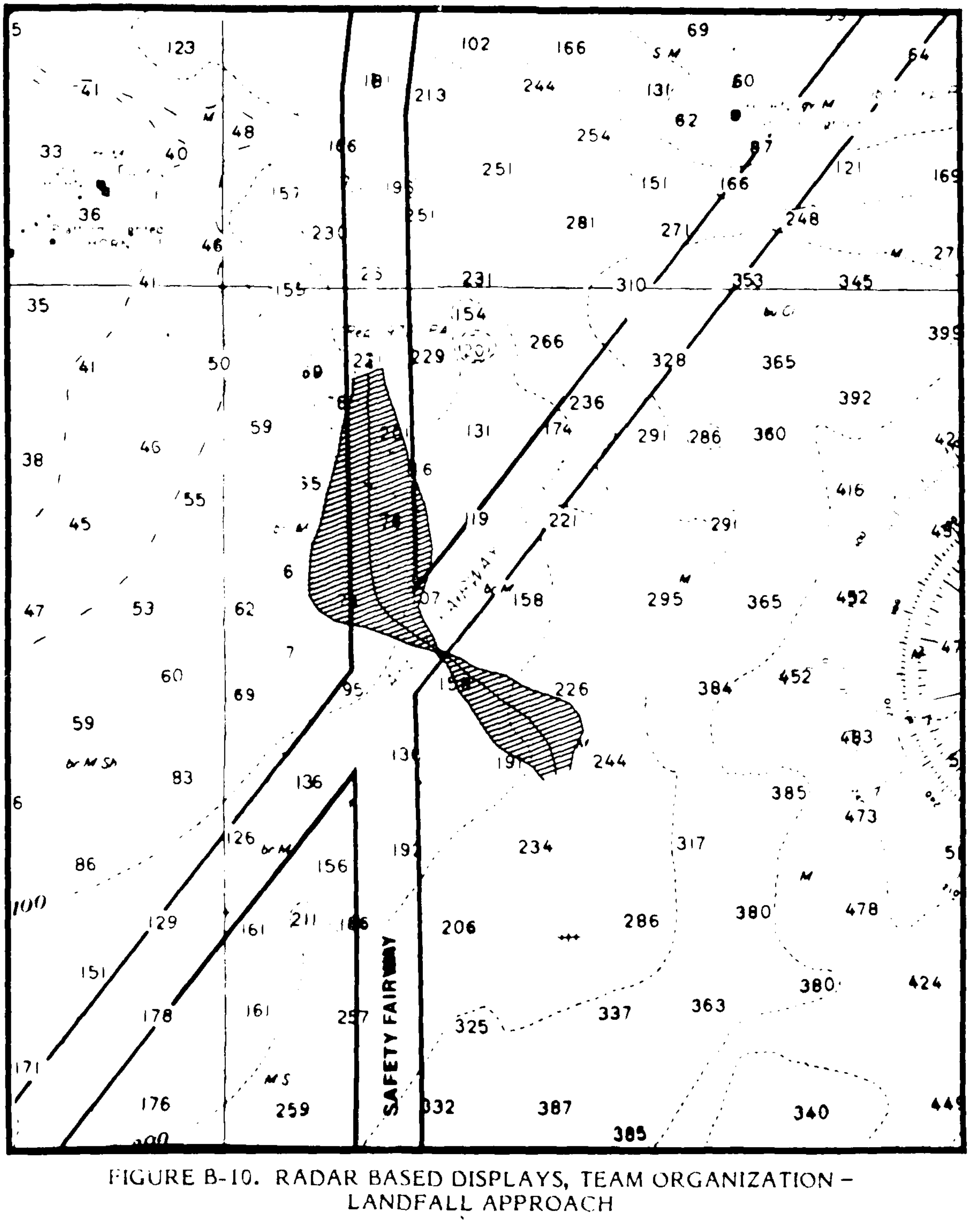


FIGURE B-10. RADAR BASED DISPLAYS, TEAM ORGANIZATION – LANDFALL APPROACH

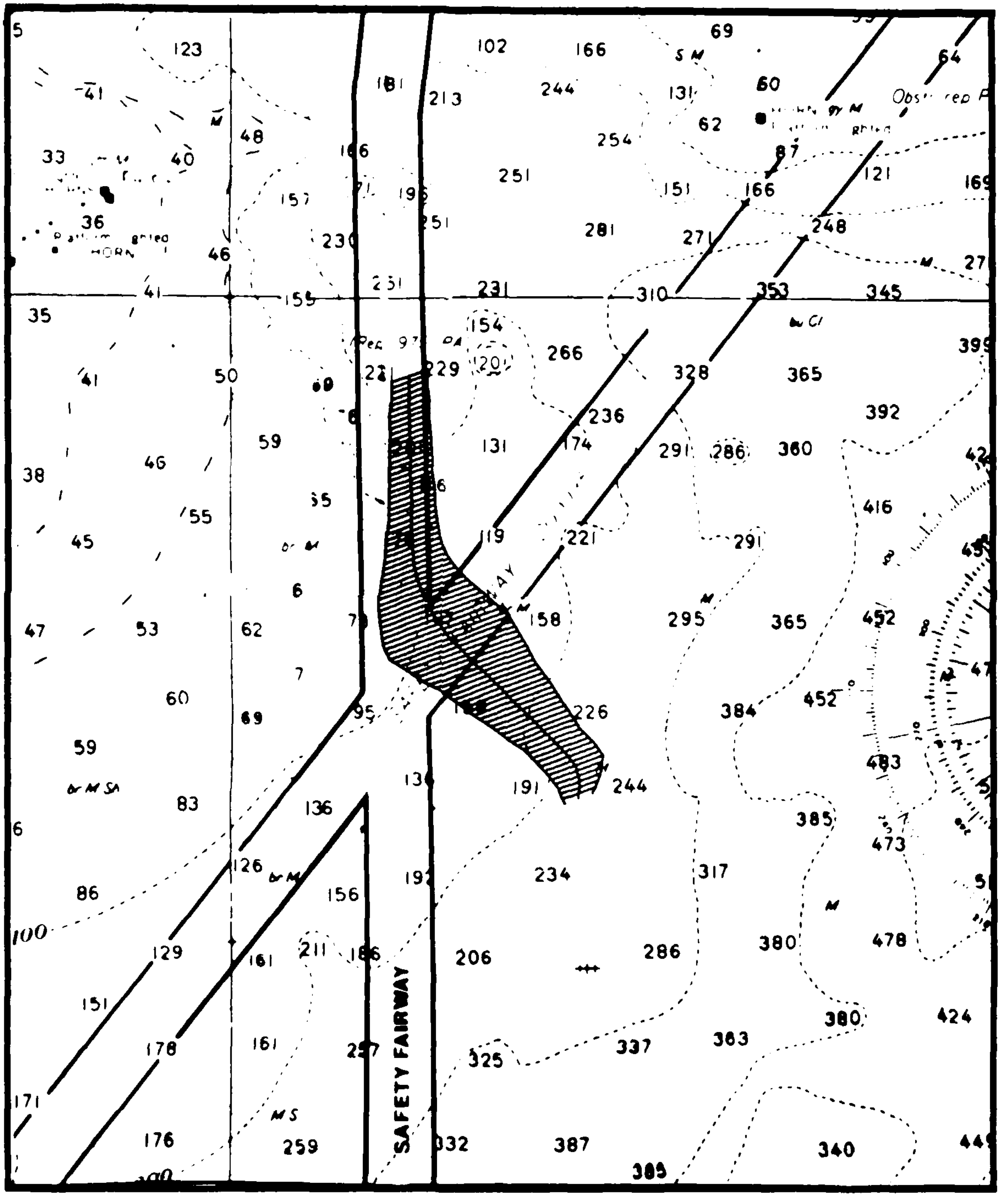


FIGURE B-11. ARPA BASED DISPLAYS, TRADITIONAL ORGANIZATION – LANDFALL APPROACH

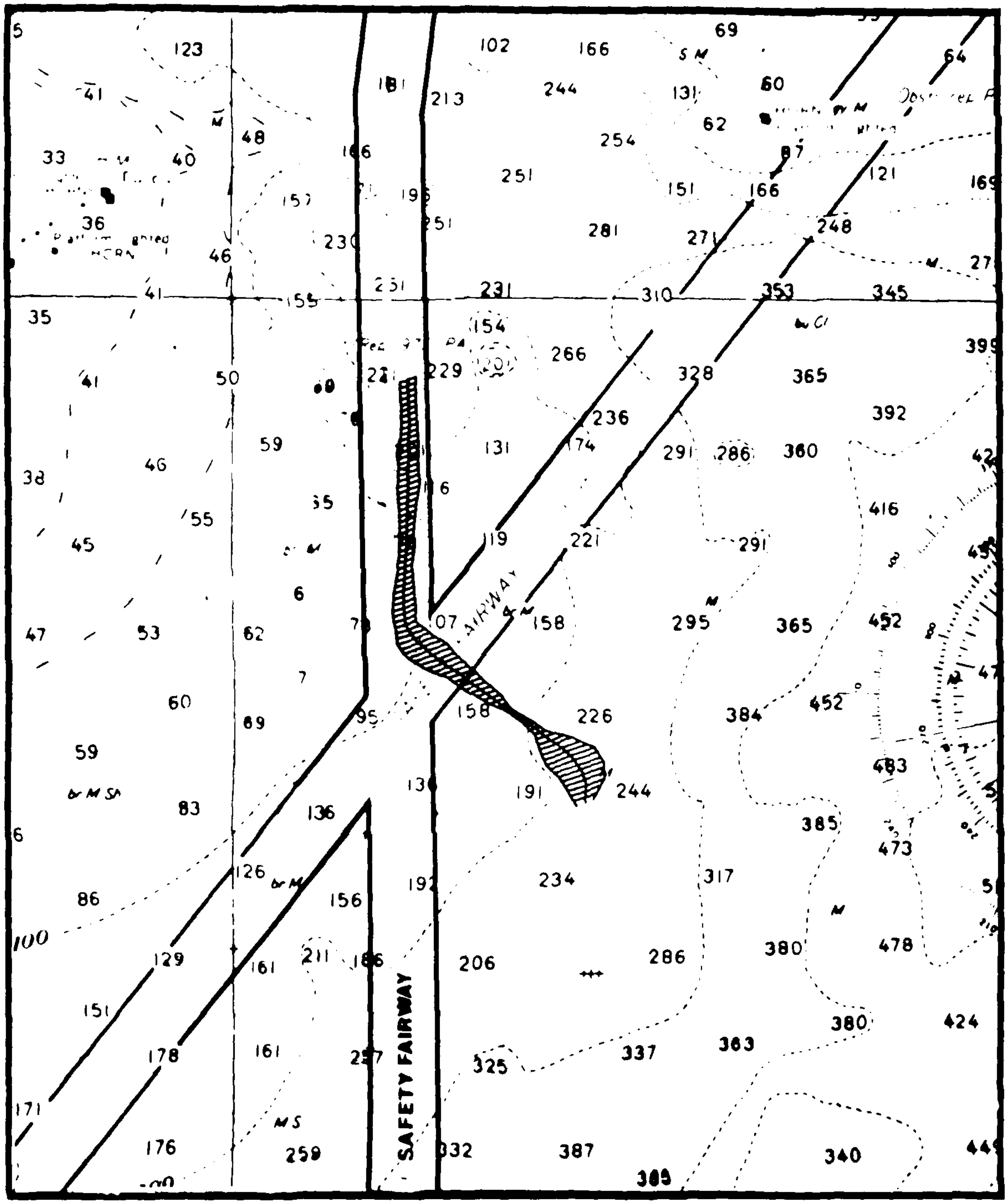


FIGURE B-12. ARPA BASED DISPLAYS, TEAM ORGANIZATION – LANDFALL APPROACH

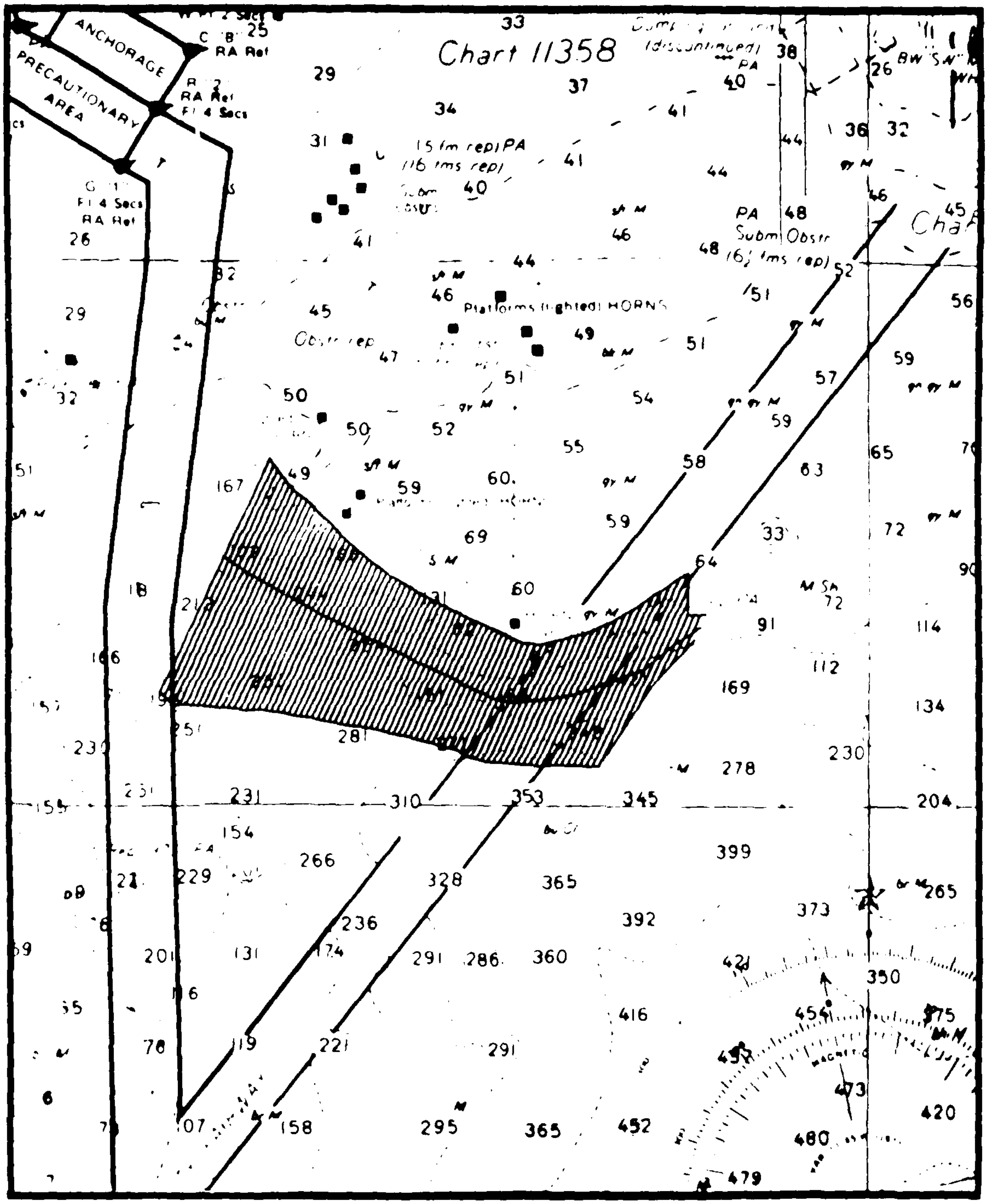


FIGURE B-13. RADAR BASED DISPLAYS – COASTWISE APPROACH

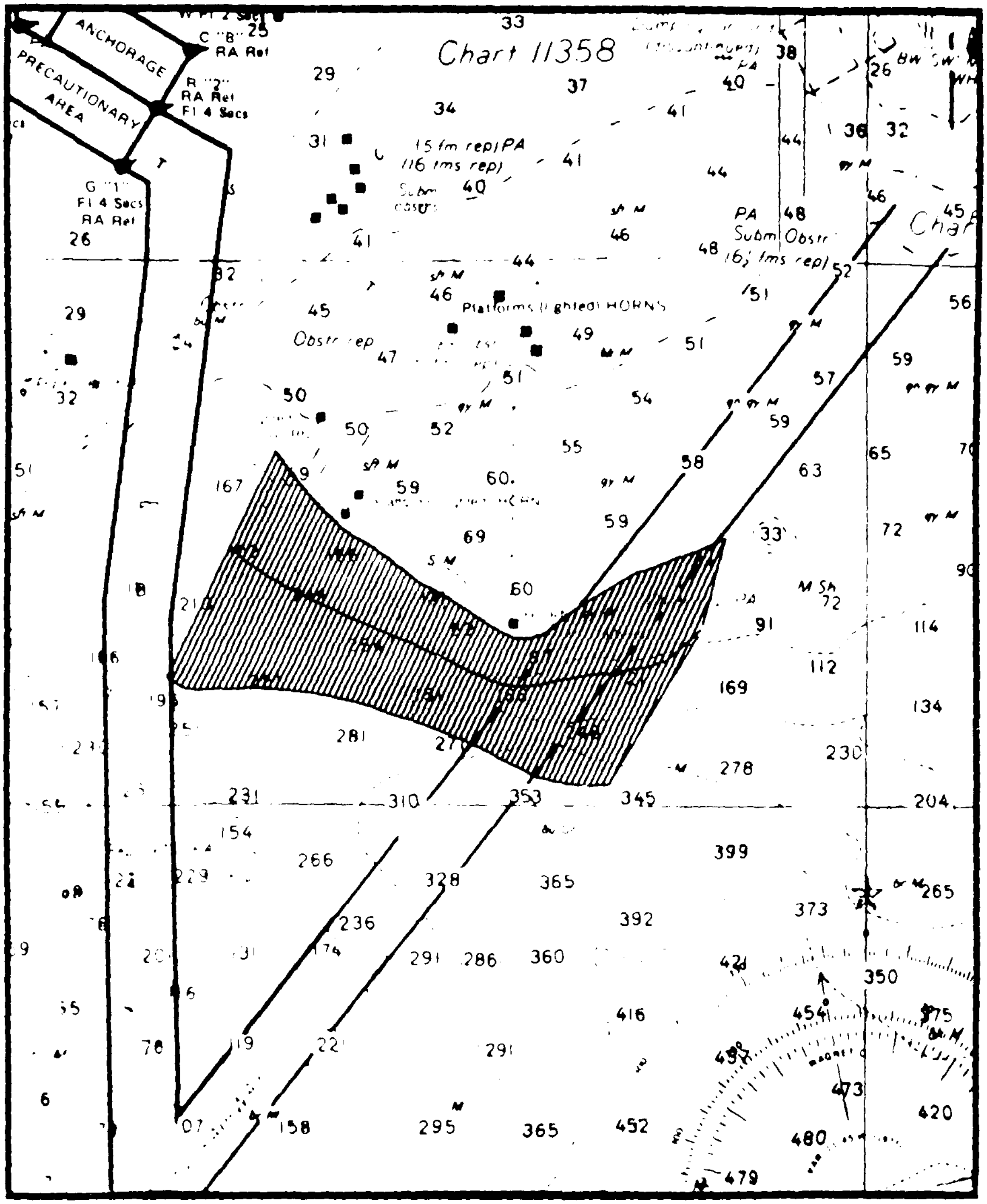


FIGURE B-14. ARPA BASED DISPLAYS – COASTWISE APPROACH

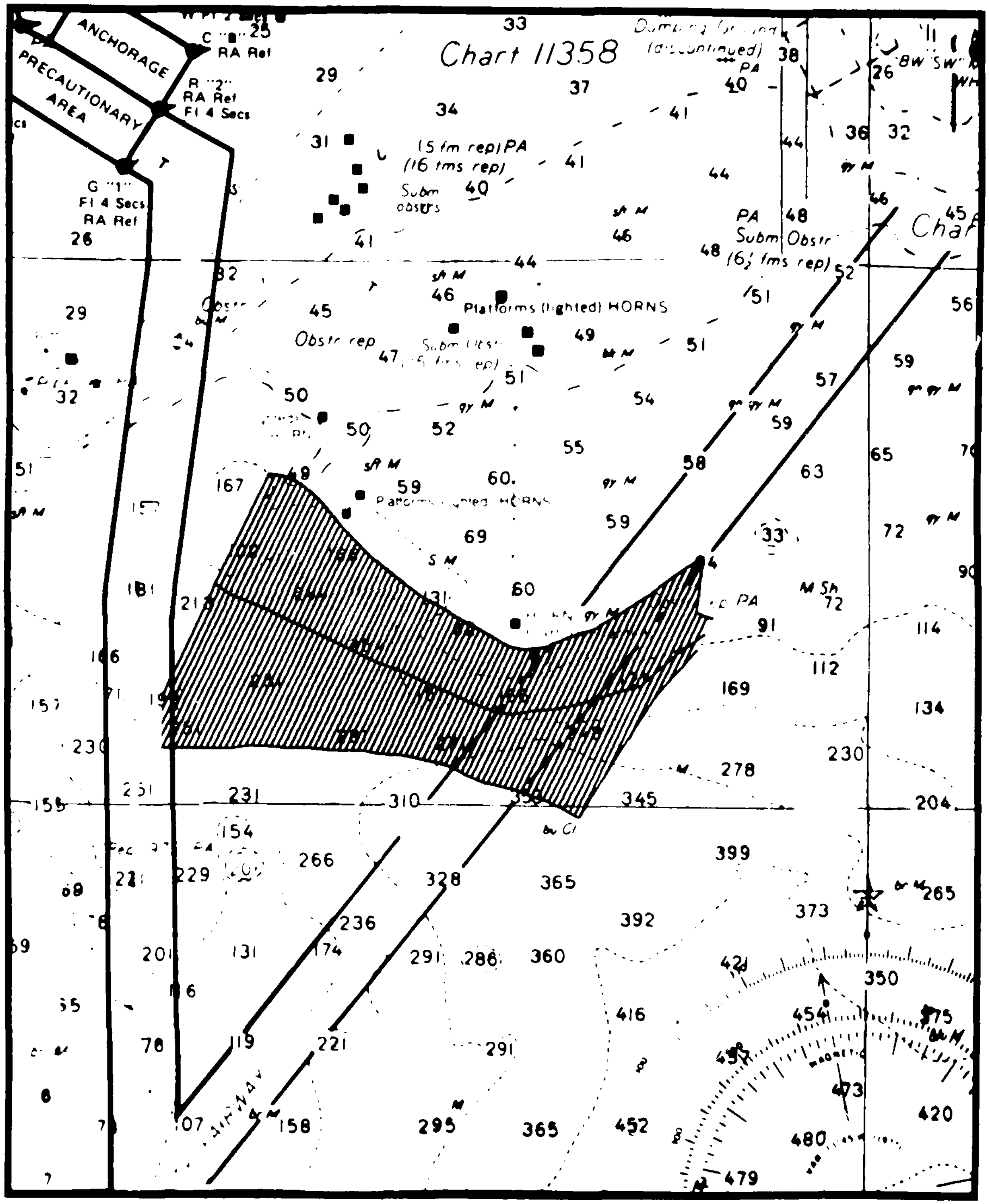


FIGURE B-15. RADAR – COASTWISE APPROACH

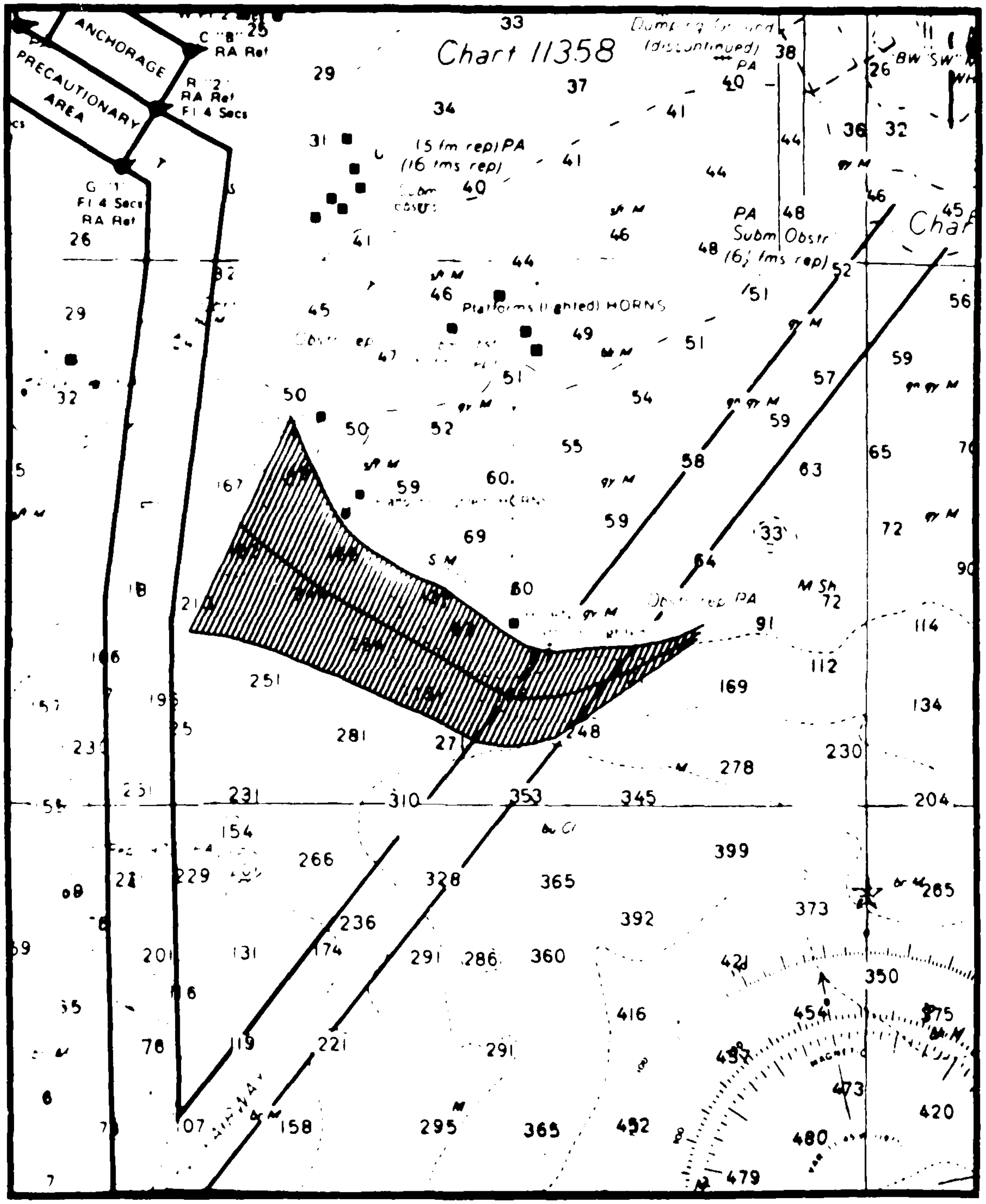


FIGURE B-16. RADAR/RACON – COASTWISE APPROACH

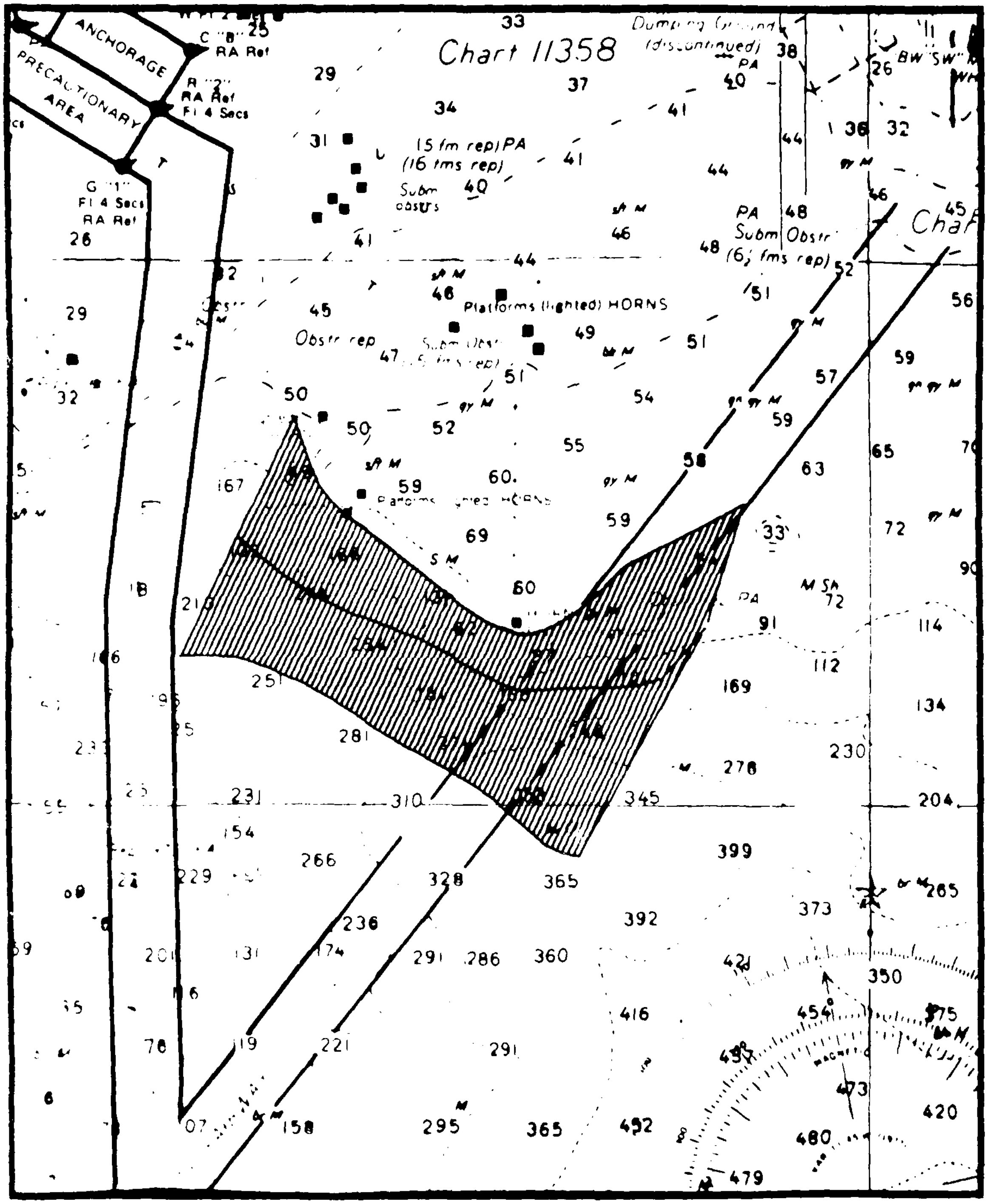


FIGURE B-17. ARPA – COASTWISE APPROACH

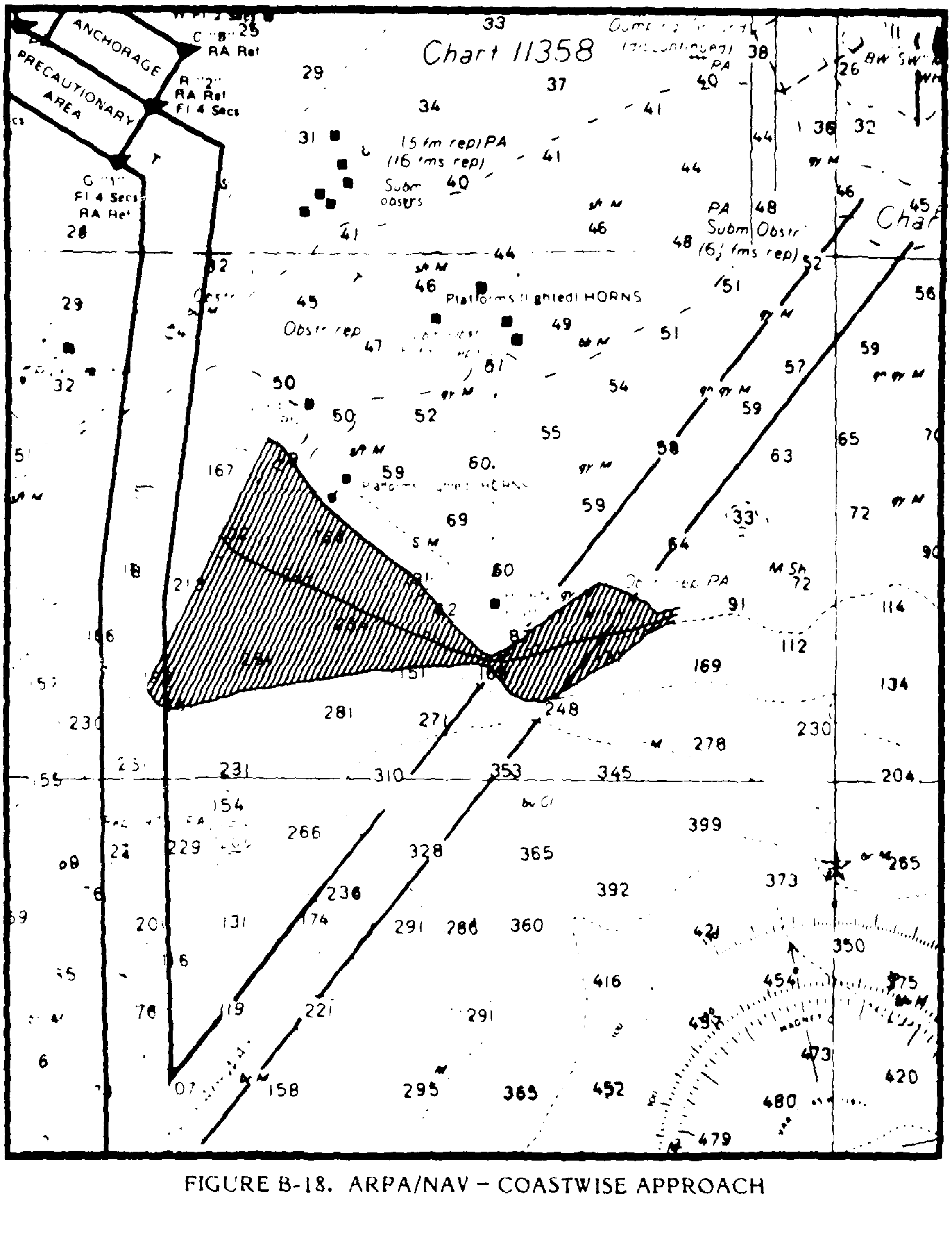


FIGURE B-18. ARPA/NAV – COASTWISE APPROACH

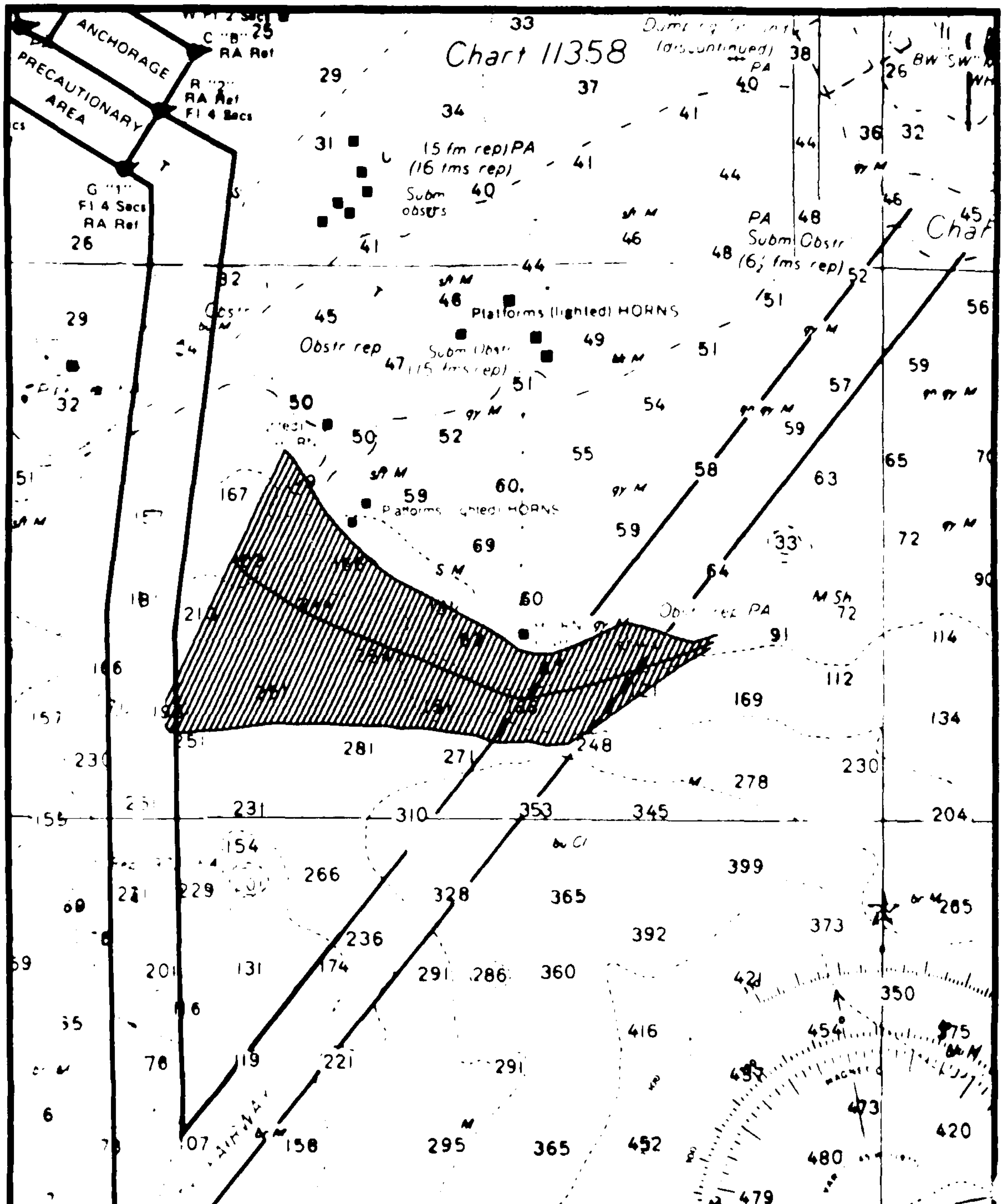


FIGURE B-19. TRADITIONAL ORGANIZATION – COASTWISE APPROACH

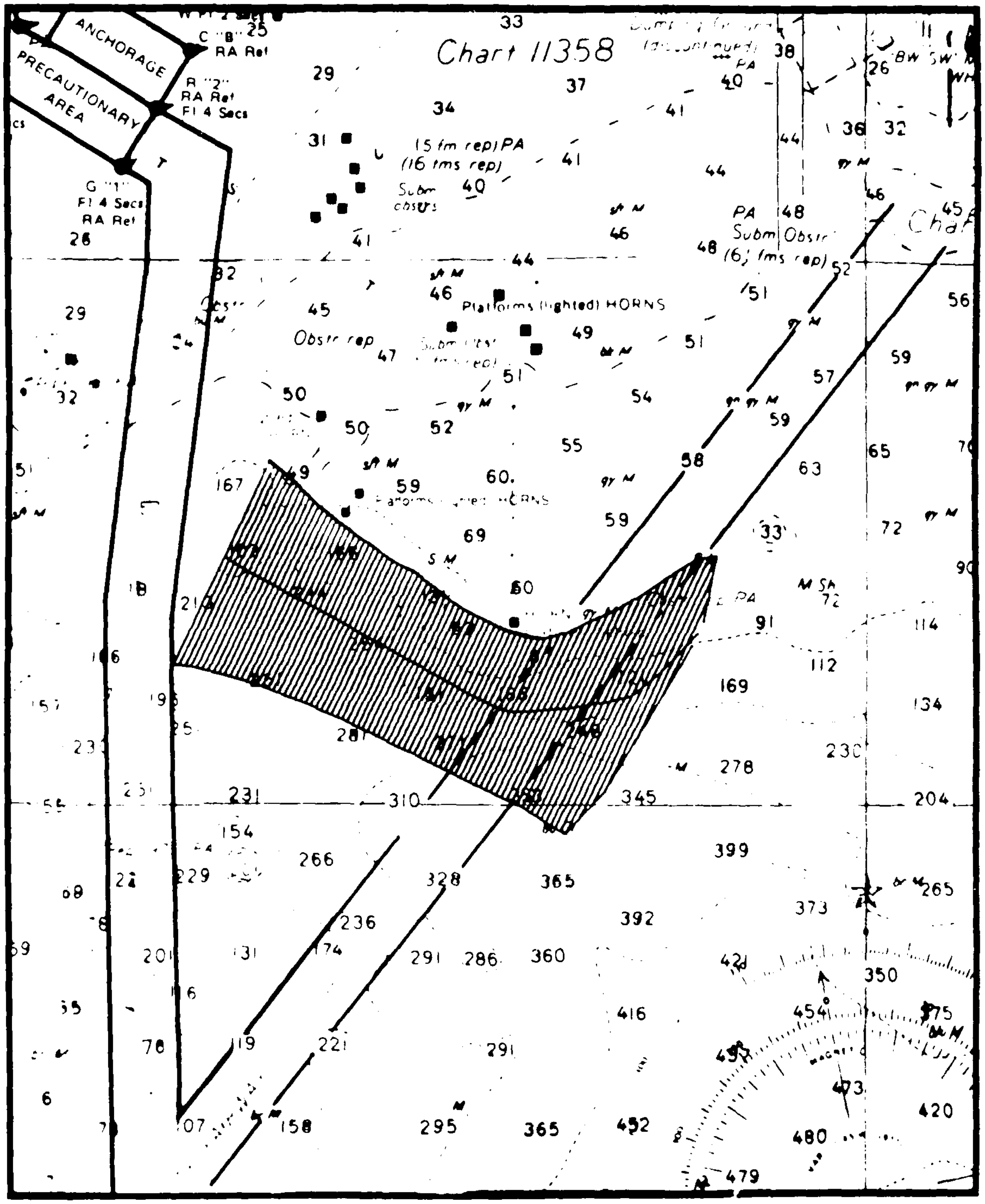


FIGURE B-20. TEAM ORGANIZATION – COASTWISE APPROACH

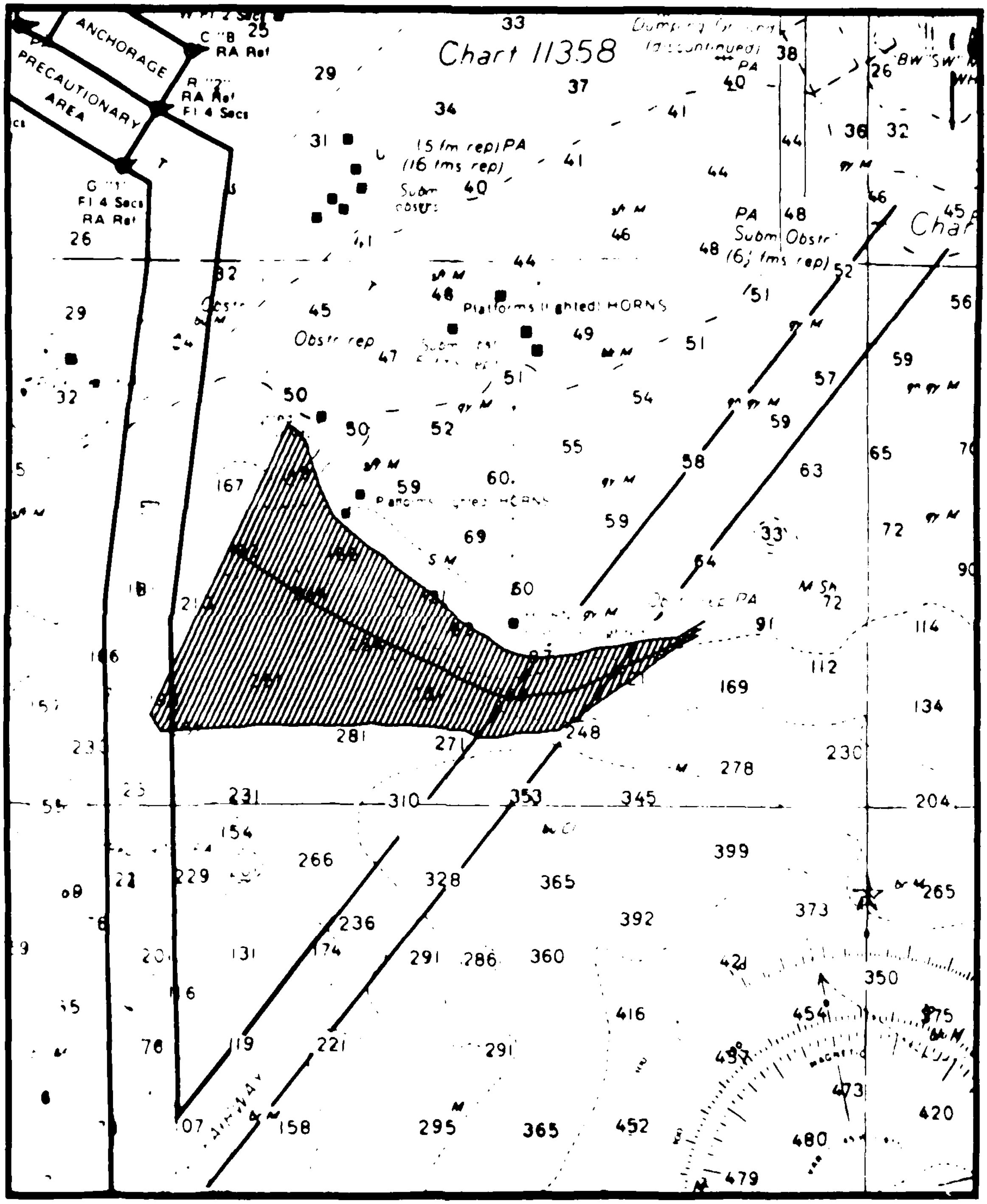


FIGURE B-21. RADAR BASED DISPLAYS, TRADITIONAL ORGANIZATION – COASTWISE APPROACH

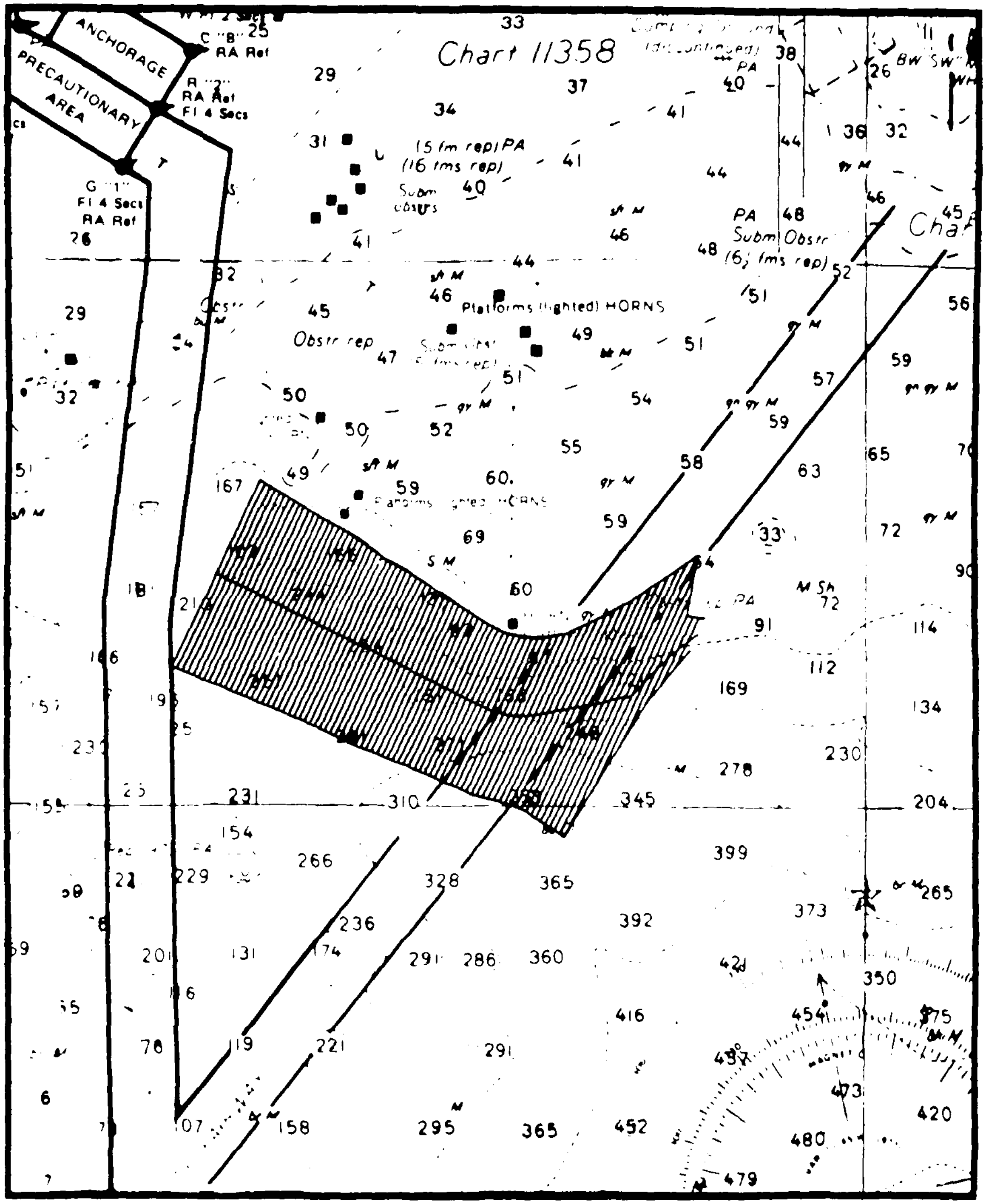


FIGURE B-22. RADAR BASED DISPLAYS, TEAM ORGANIZATION – COASTWISE APPROACH

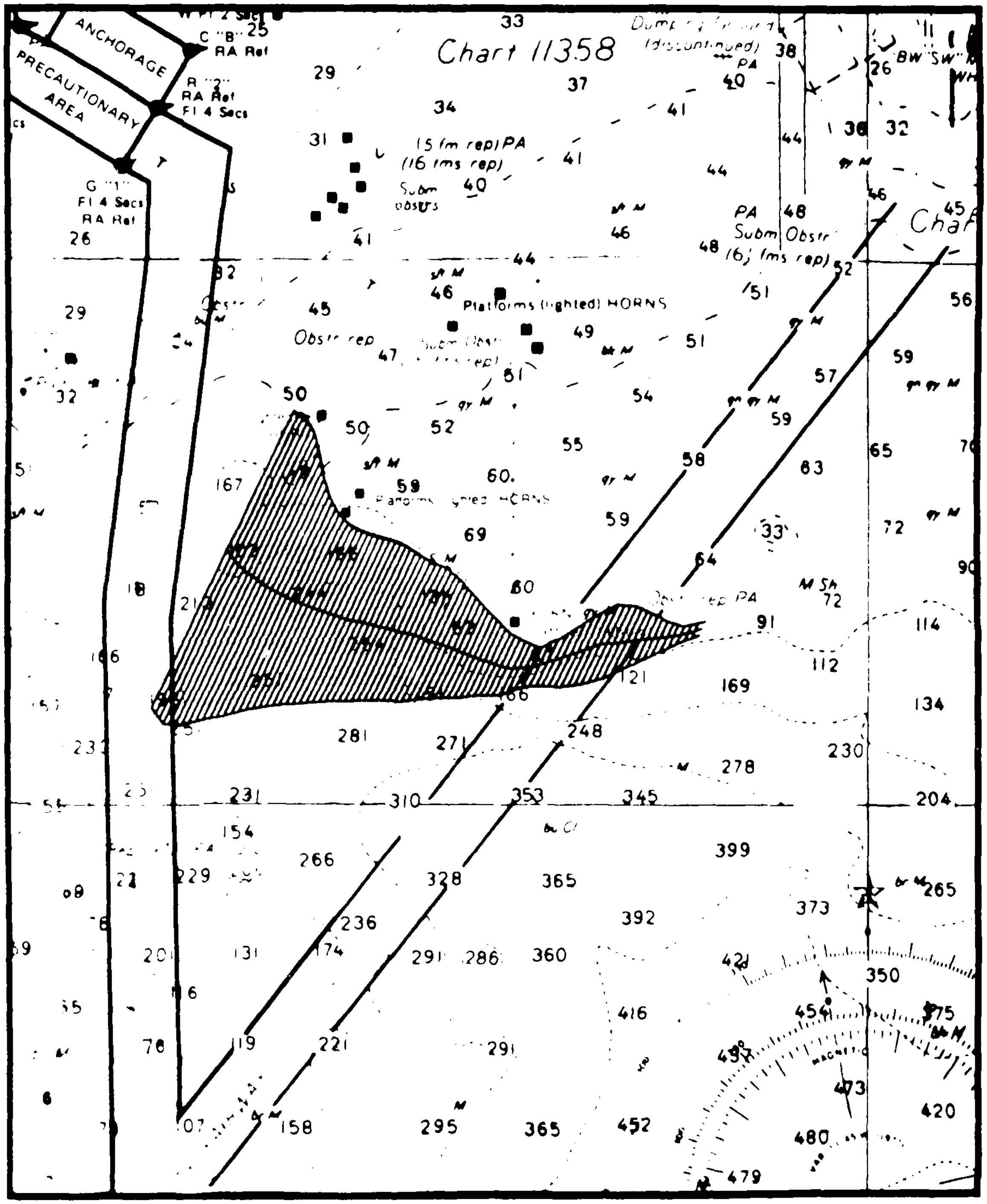


FIGURE B-23. ARPA BASED DISPLAYS, TRADITIONAL ORGANIZATION – COASTWISE APPROACH

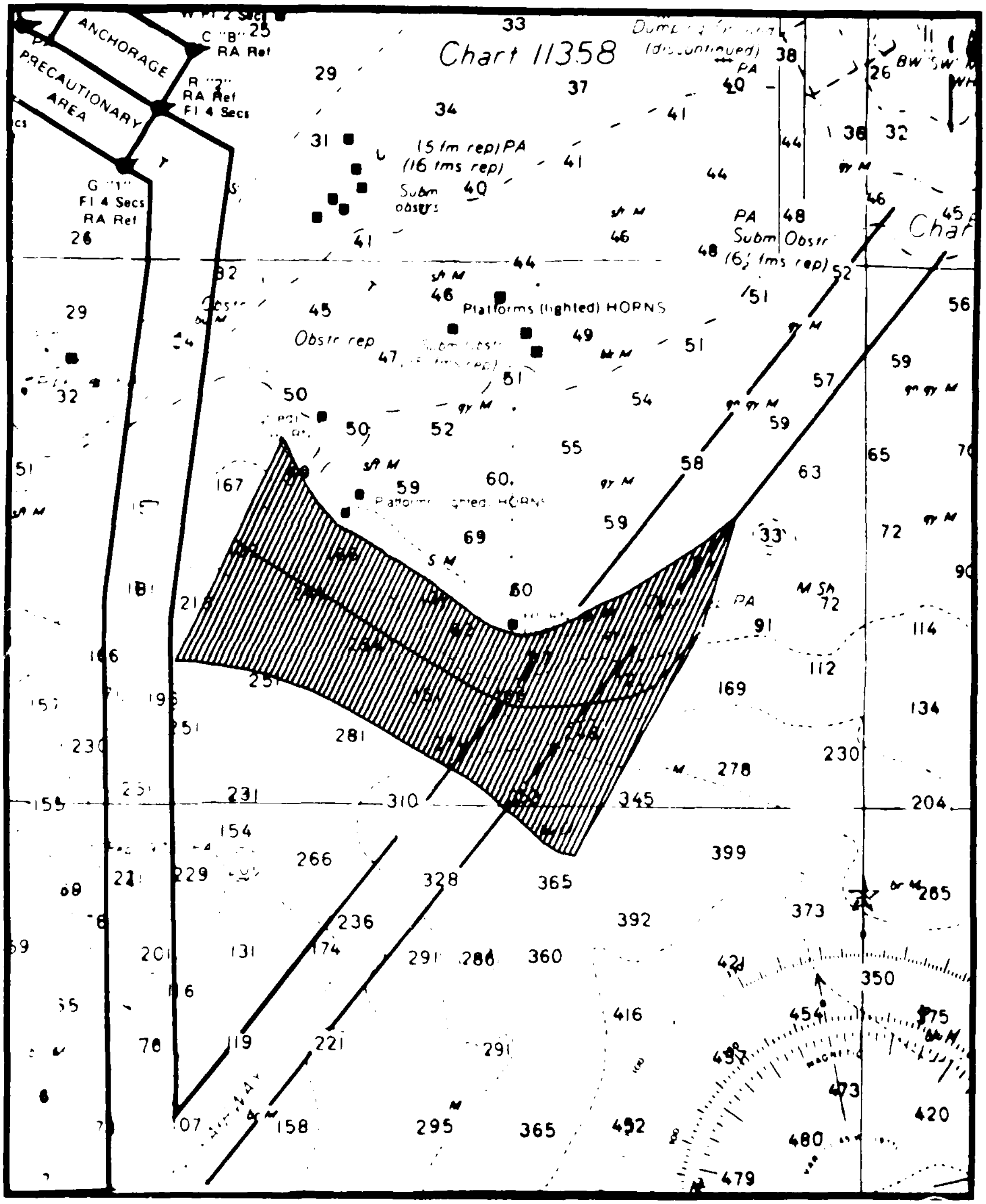


FIGURE B-24. ARPA BASED DISPLAYS, TEAM ORGANIZATION – COASTWISE APPROACH

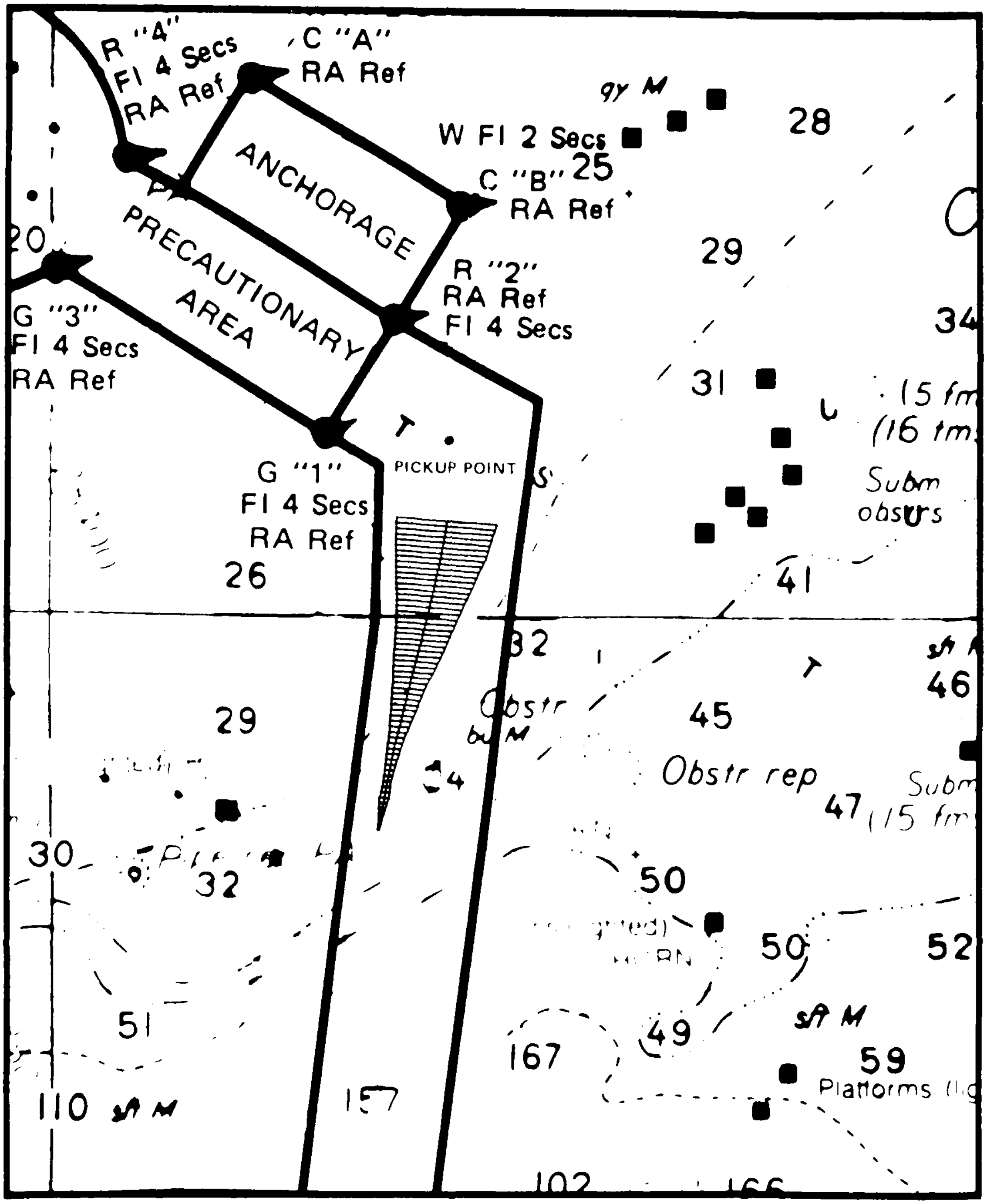


FIGURE B-25. RADAR BASED DISPLAYS – MOORING MASTER PICKUP APPROACH

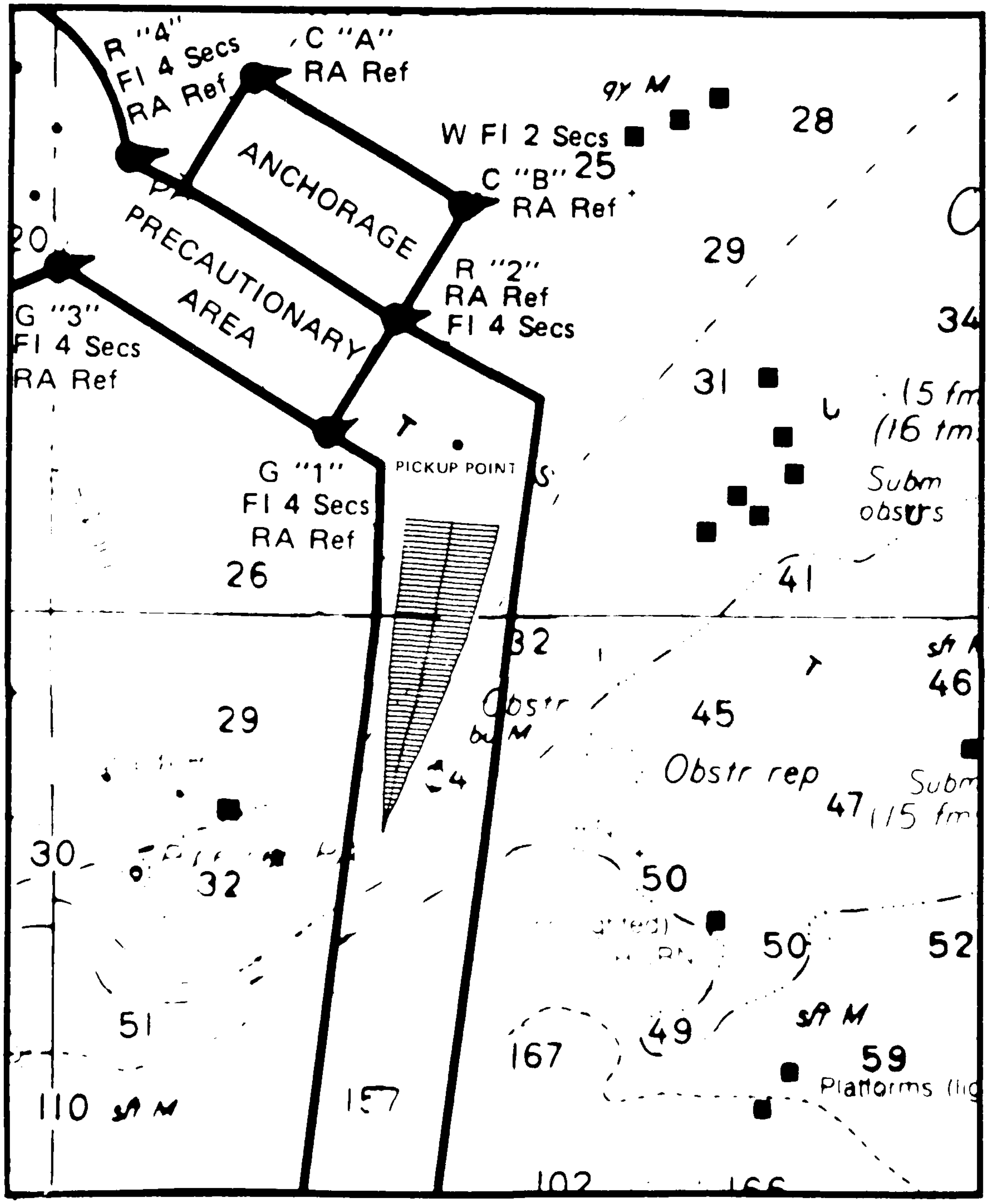


FIGURE B-26. ARPA BASED DISPLAYS – MOORING MASTER PICKUP APPROACH

FIGURE B-27. RADAR – PILOT AREA APPROACH

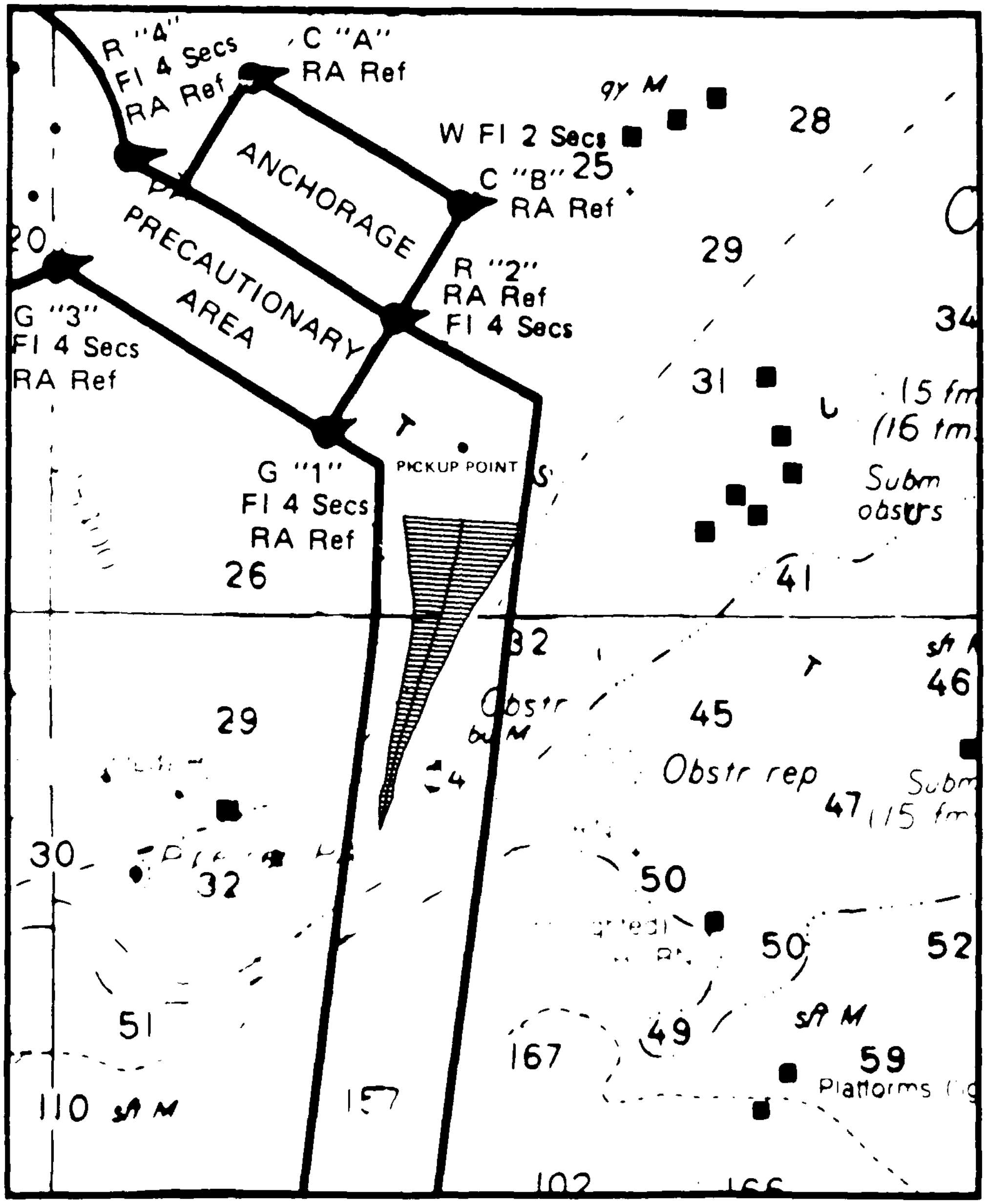


FIGURE B-27. RADAR – MOORING MASTER PICKUP APPROACH

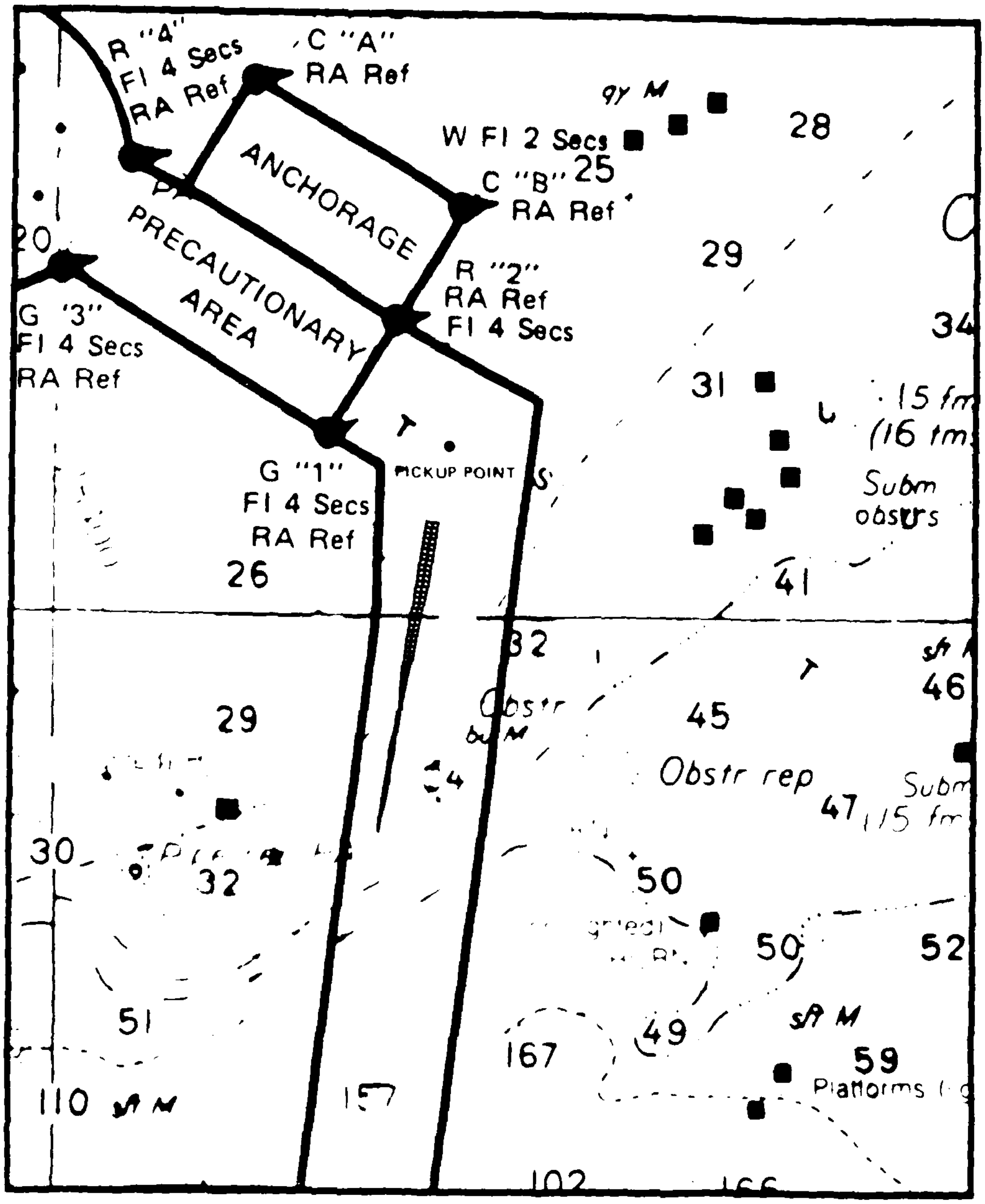


FIGURE B-28. RADAR/RACON – MOORING MASTER PICKUP APPROACH

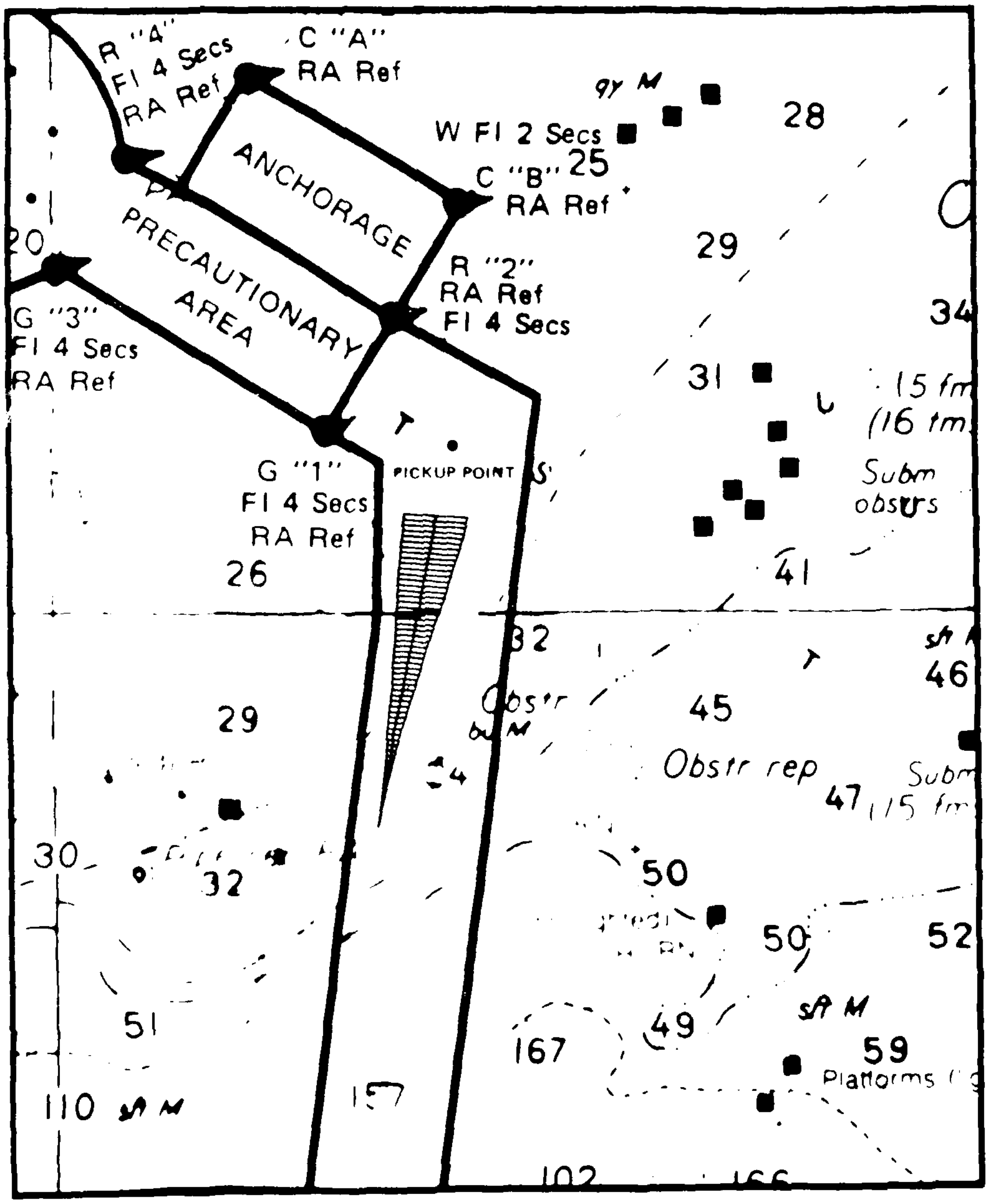


FIGURE B-29. ARPA – MOORING MASTER PICKUP APPROACH

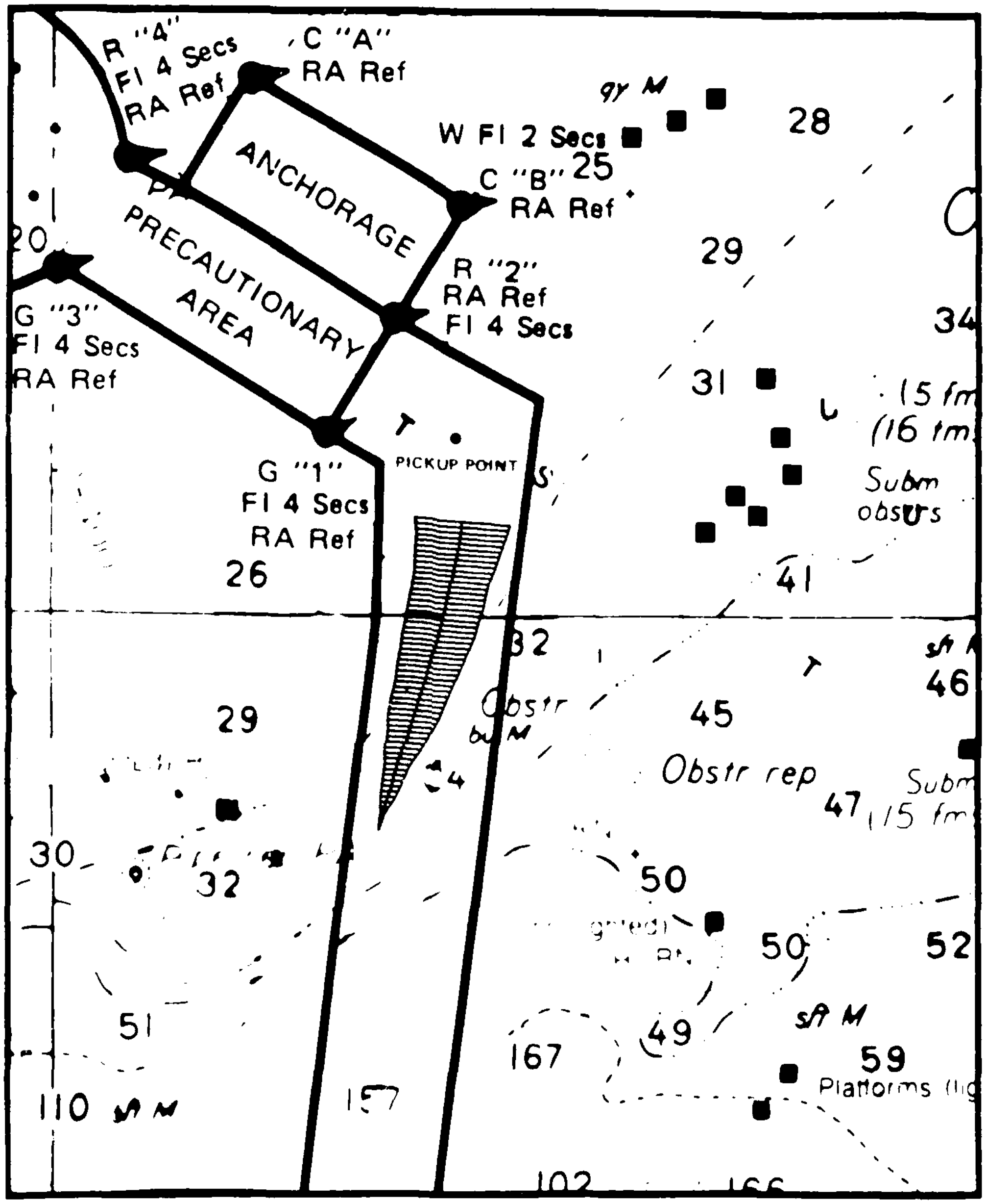


FIGURE B-30. ARPA/NAV – MOORING MASTER PICKUP APPROACH

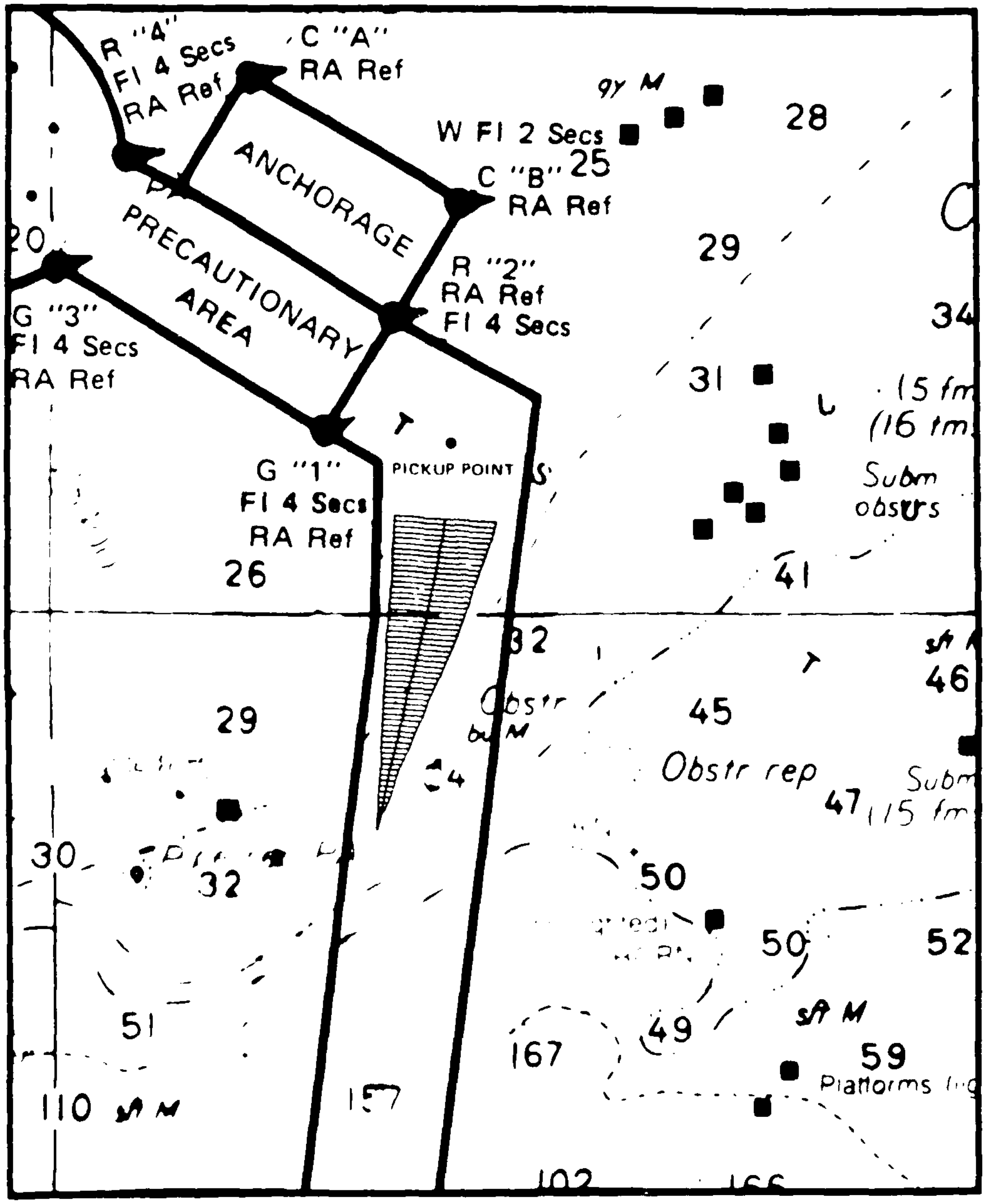


FIGURE B-31. TRADITIONAL ORGANIZATION – MOORING MASTER PICKUP APPROACH

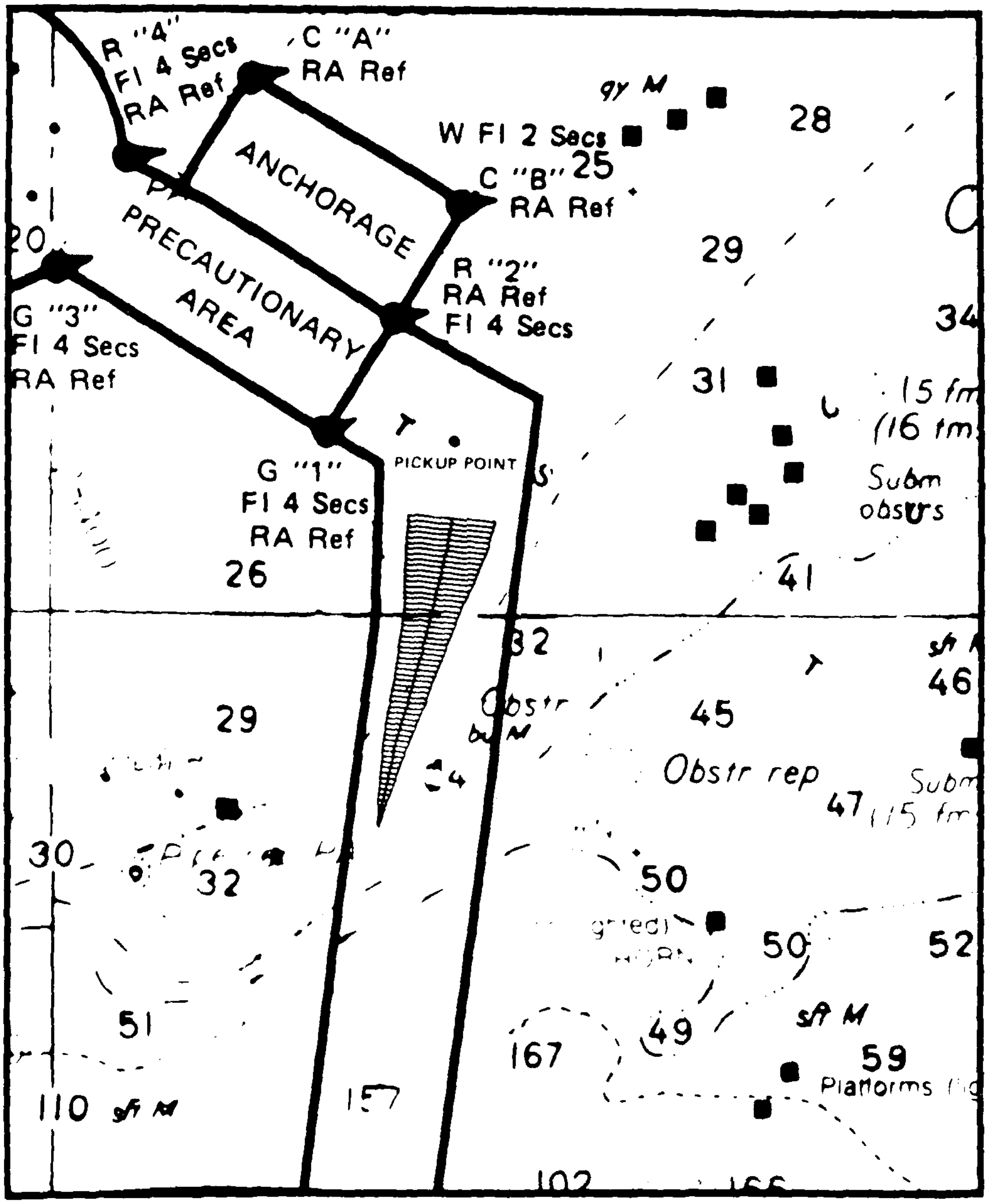


FIGURE B-32. TEAM ORGANIZATION –
MOORING MASTER PICKUP APPROACH

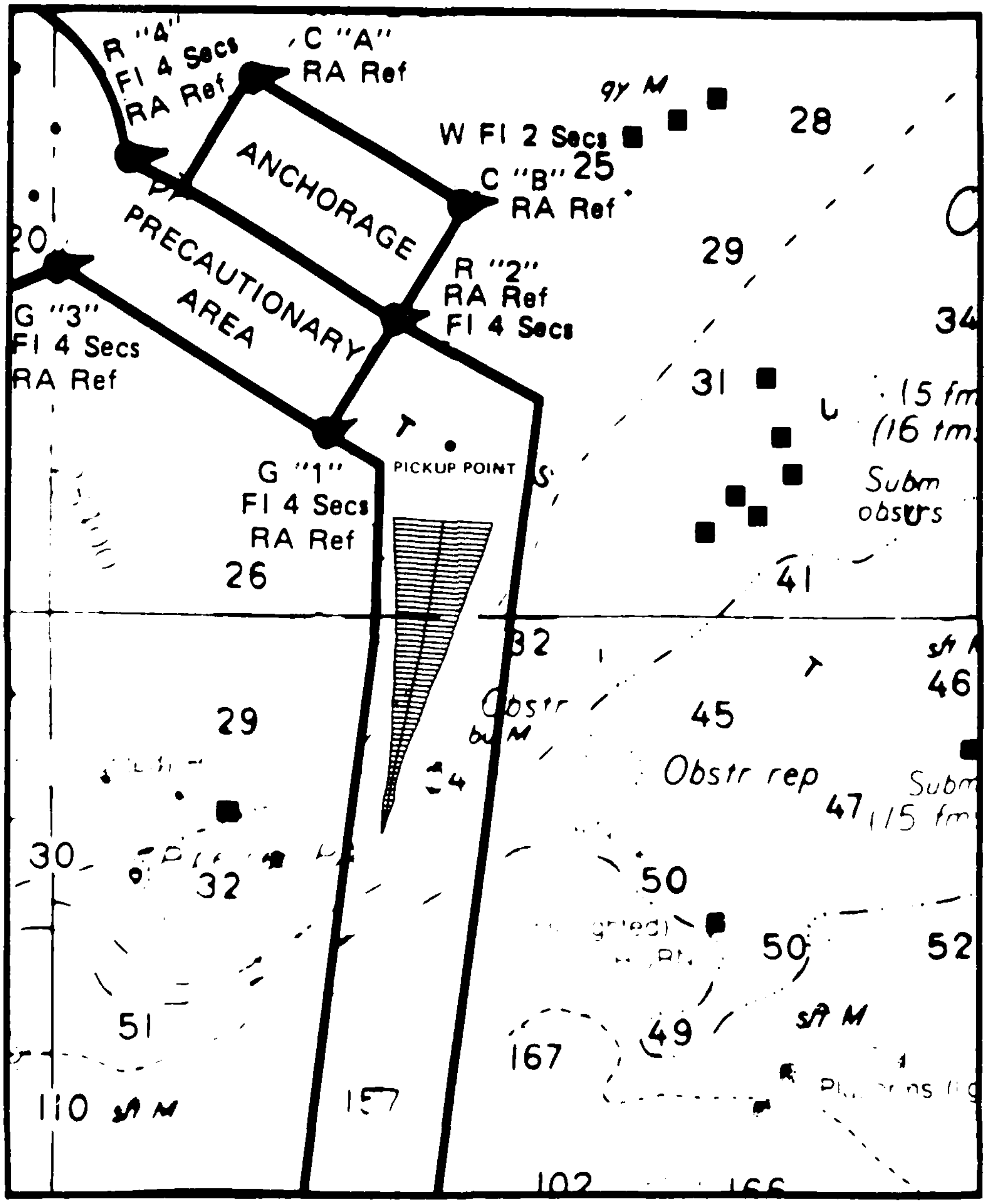


FIGURE B-33. RADAR BASED DISPLAYS, TRADITIONAL ORGANIZATION – MOORING MASTER PICKUP APPROACH

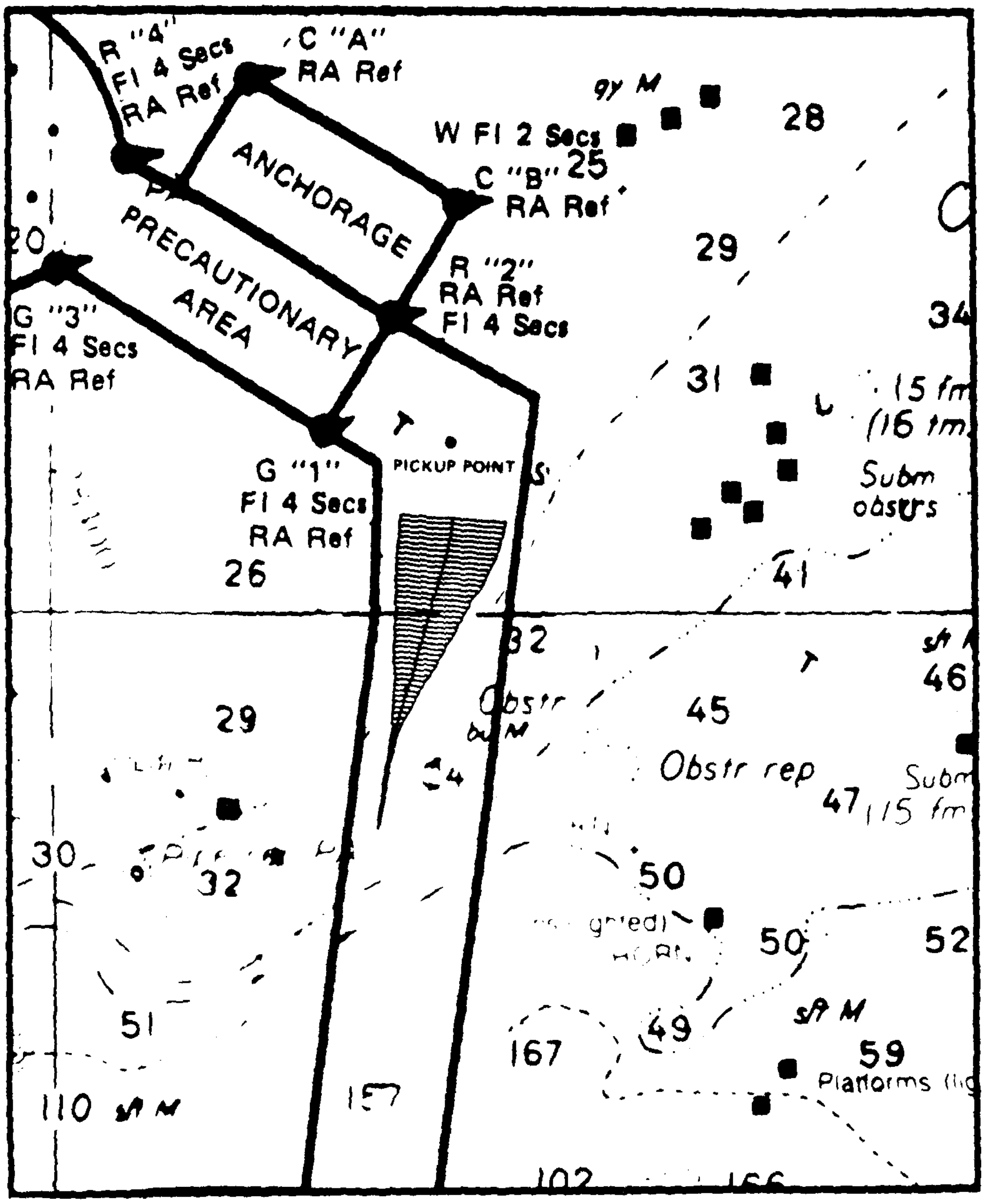


FIGURE B-34. RADAR BASED DISPLAYS, TEAM ORGANIZATION – MOORING MASTER PICKUP APPROACH

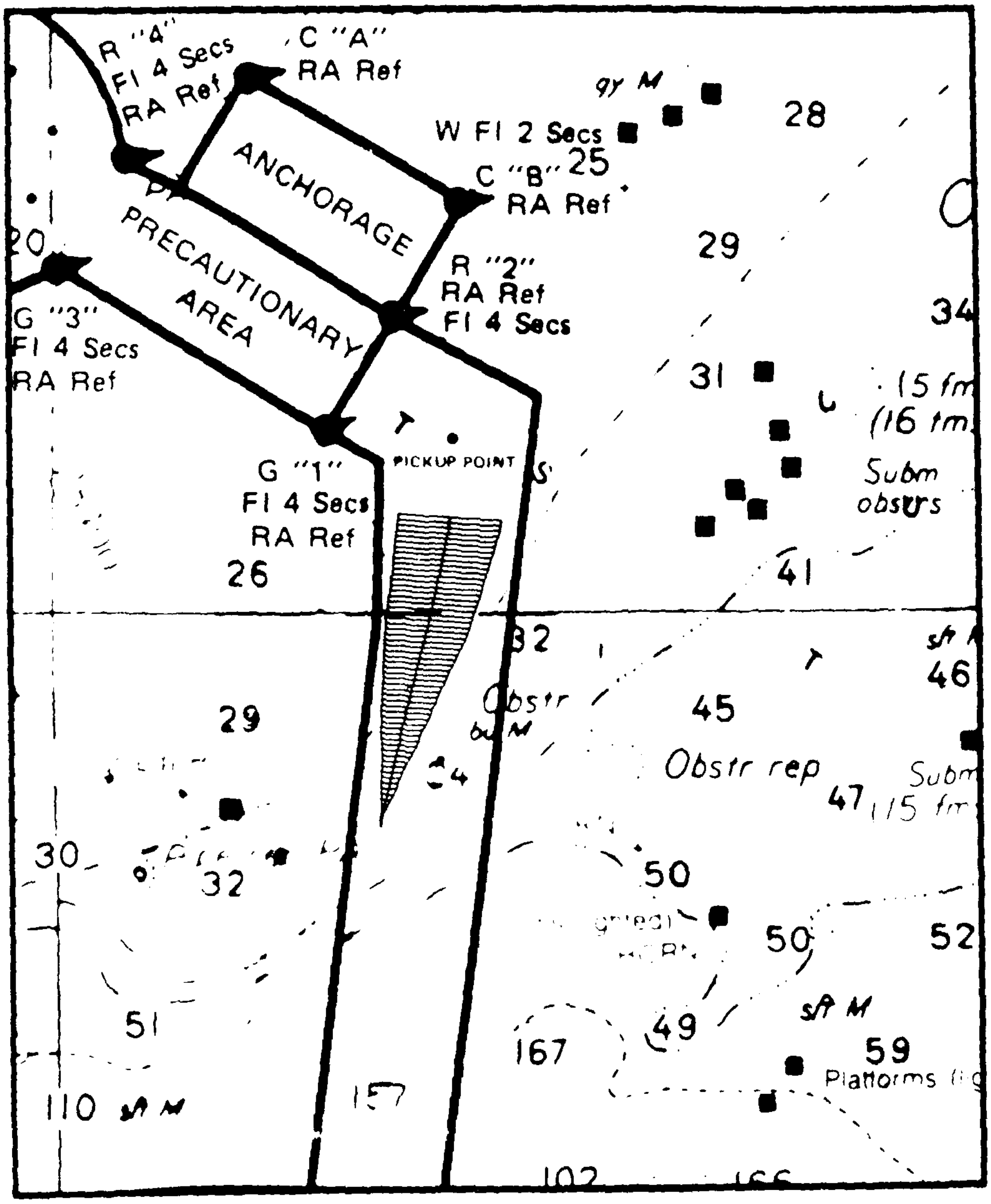


FIGURE B-35. ARPA BASED DISPLAYS, TRADITIONAL ORGANIZATION – MOORING MASTER PICKUP APPROACH

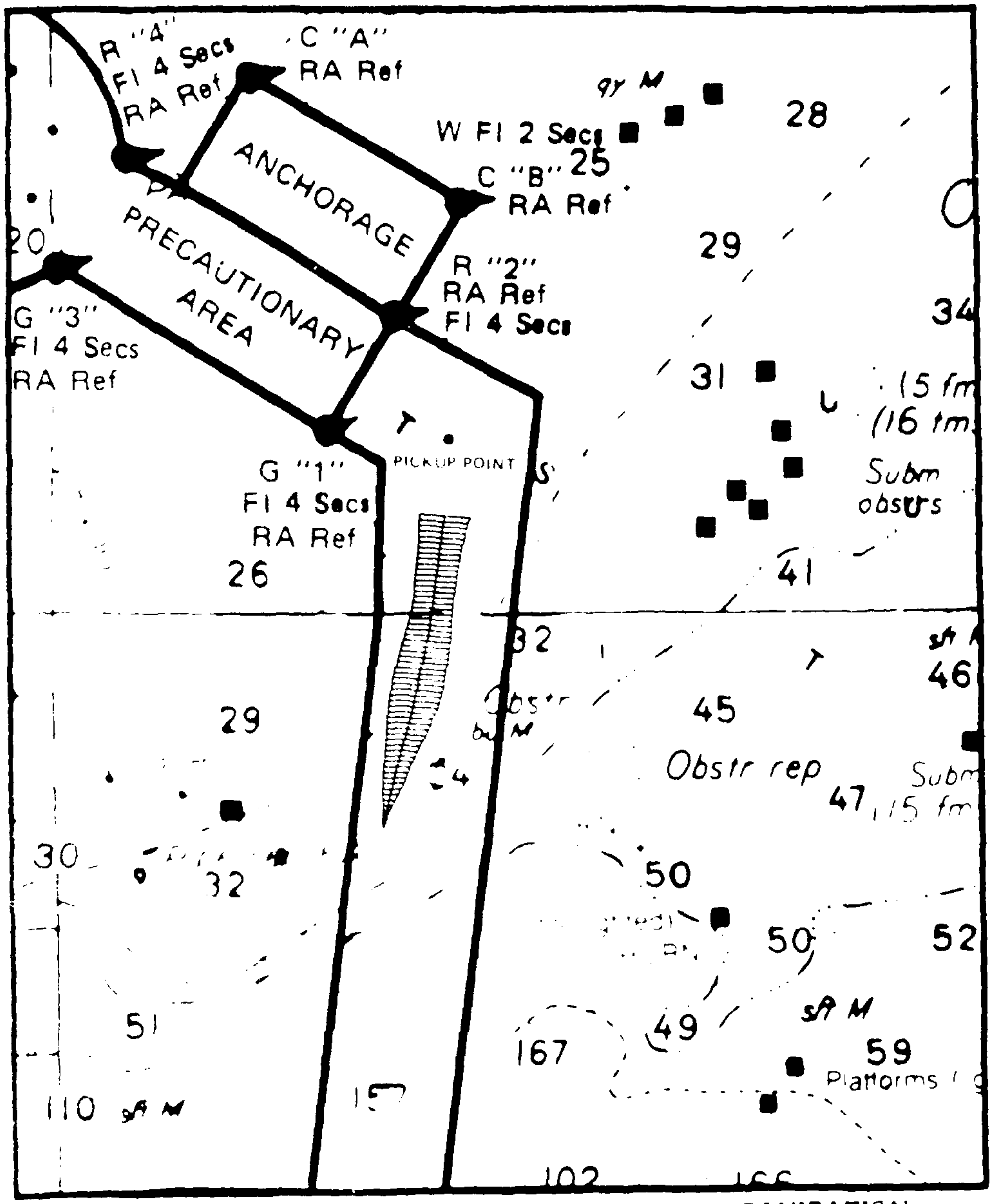


FIGURE B-36. ARPA BASED DISPLAYS, TEAM ORGANIZATION – MOORING MASTER PICKUP APPROACH

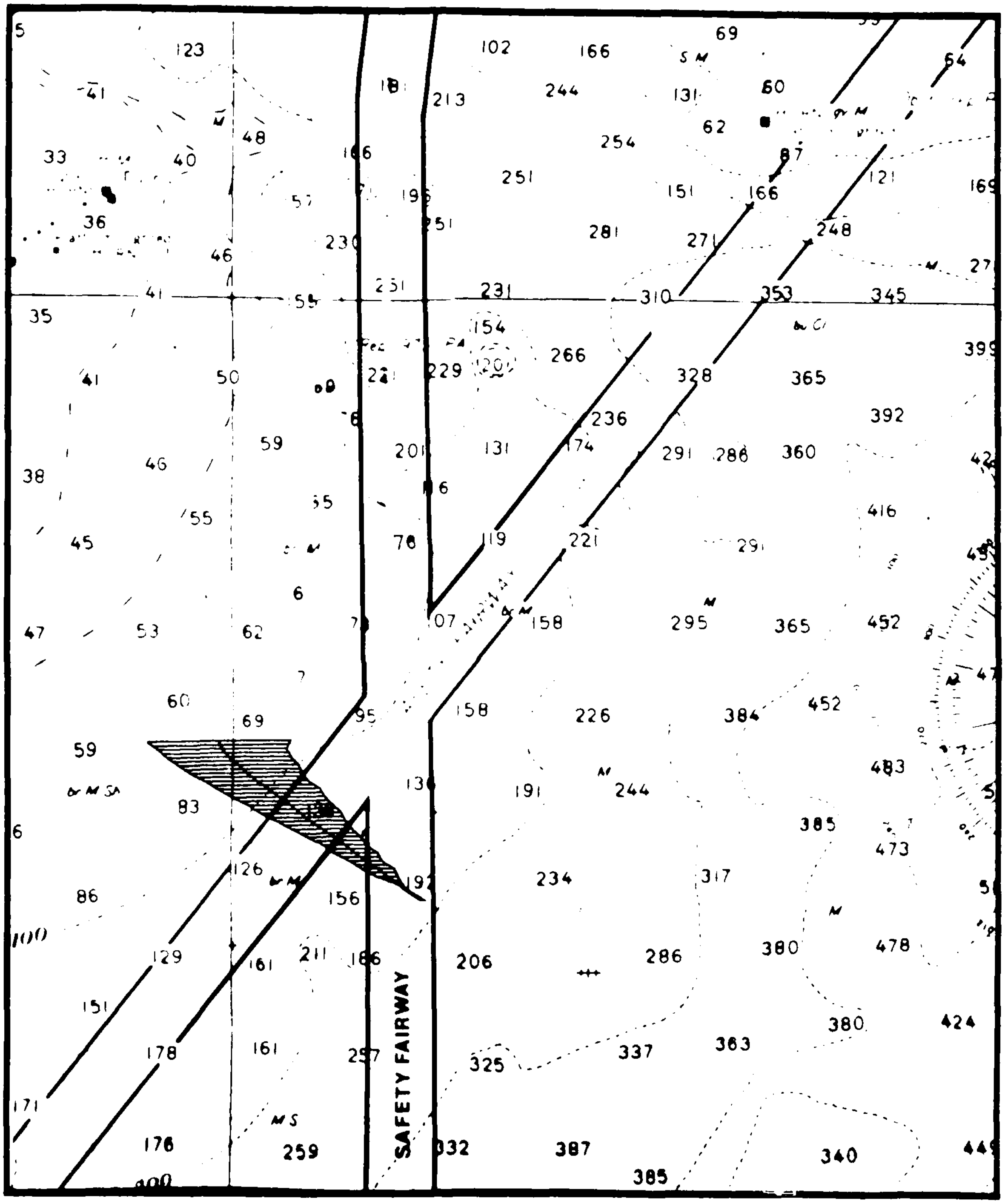


FIGURE B-37. RADAR – DEGRADED DEAD RECKONING APPROACH

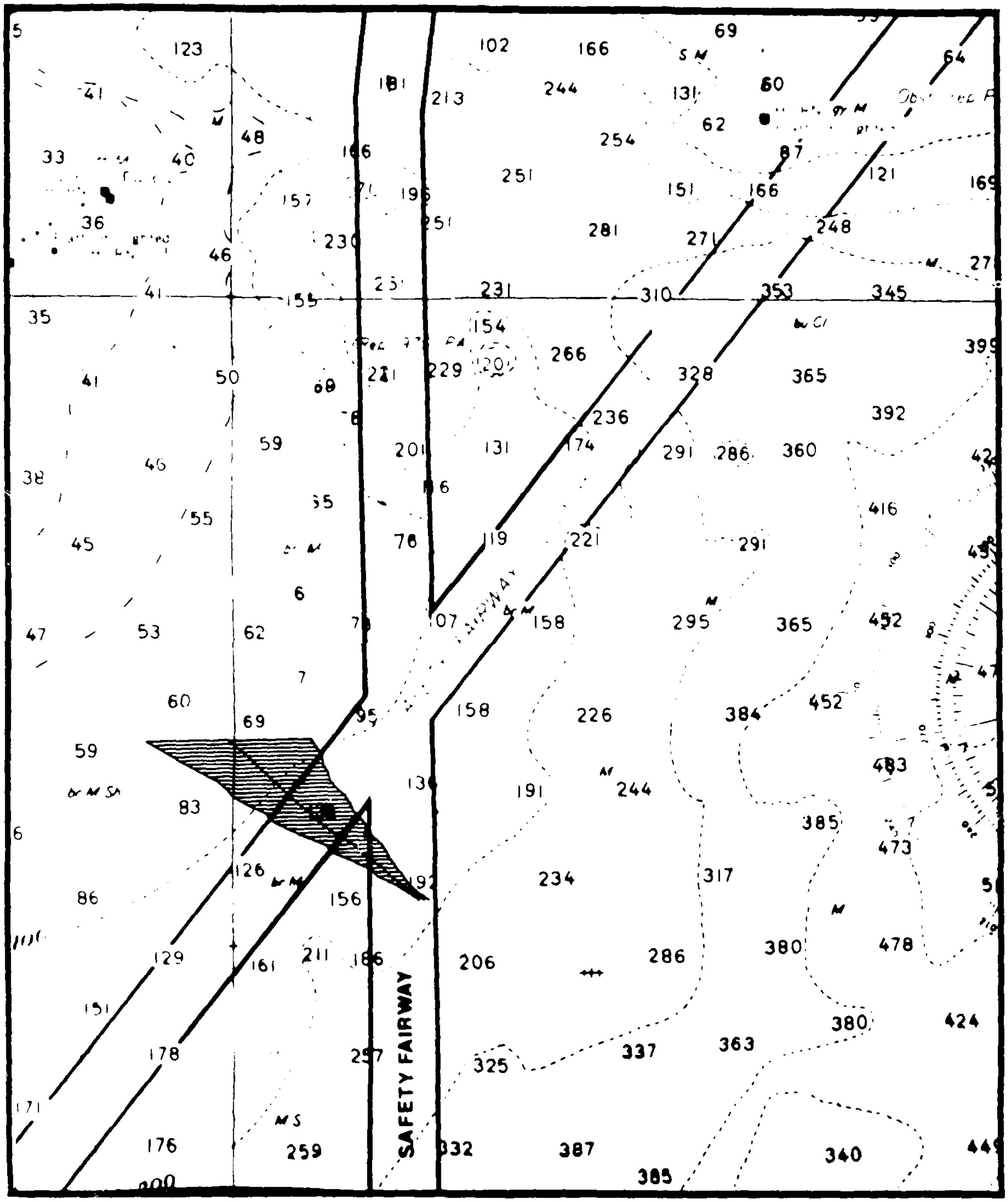


FIGURE B-38. RADAR/RACON – DEGRADED DEAD RECKONING APPROACH

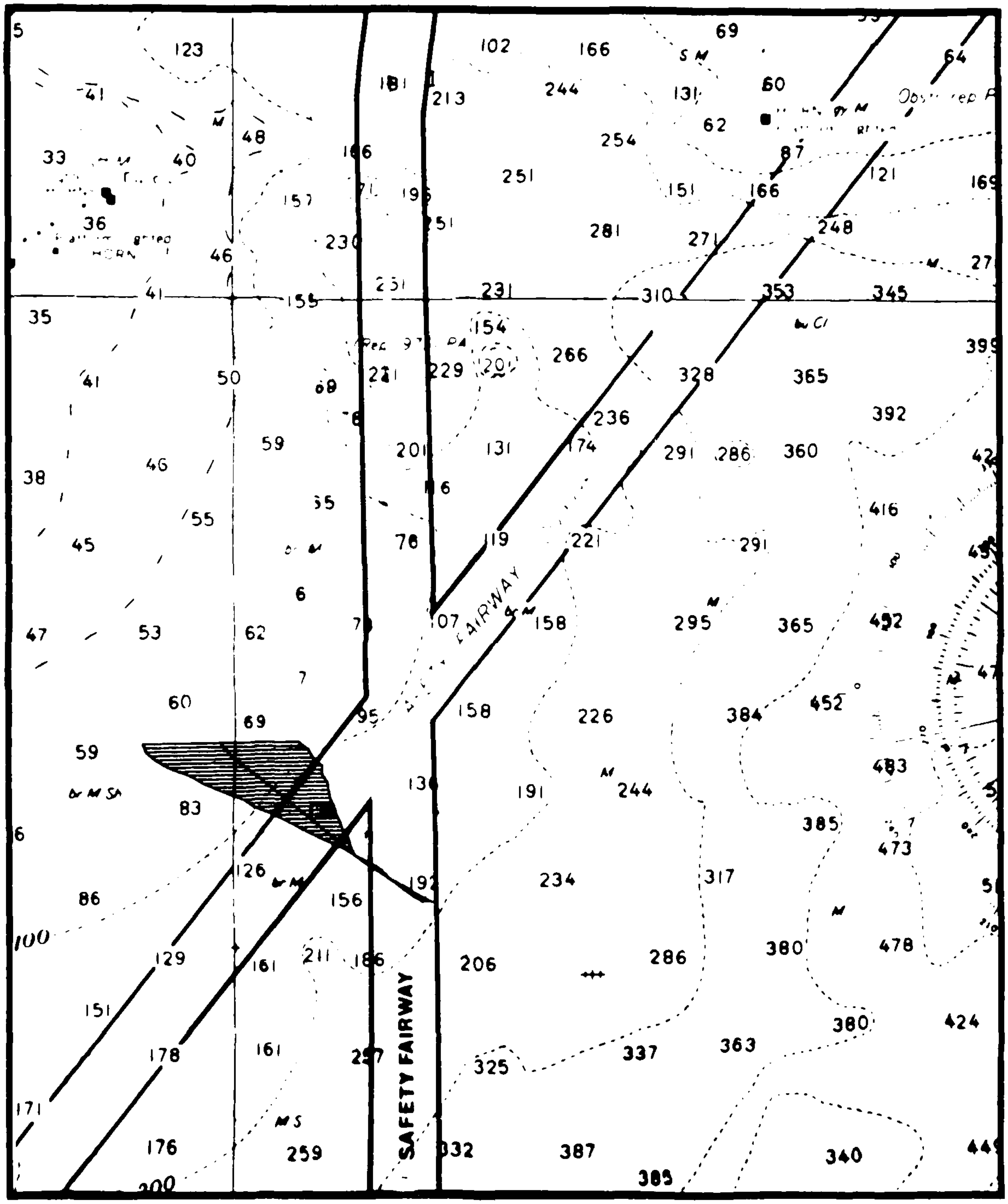


FIGURE B-39. ARPA – DEGRADED DEAD RECKONING APPROACH

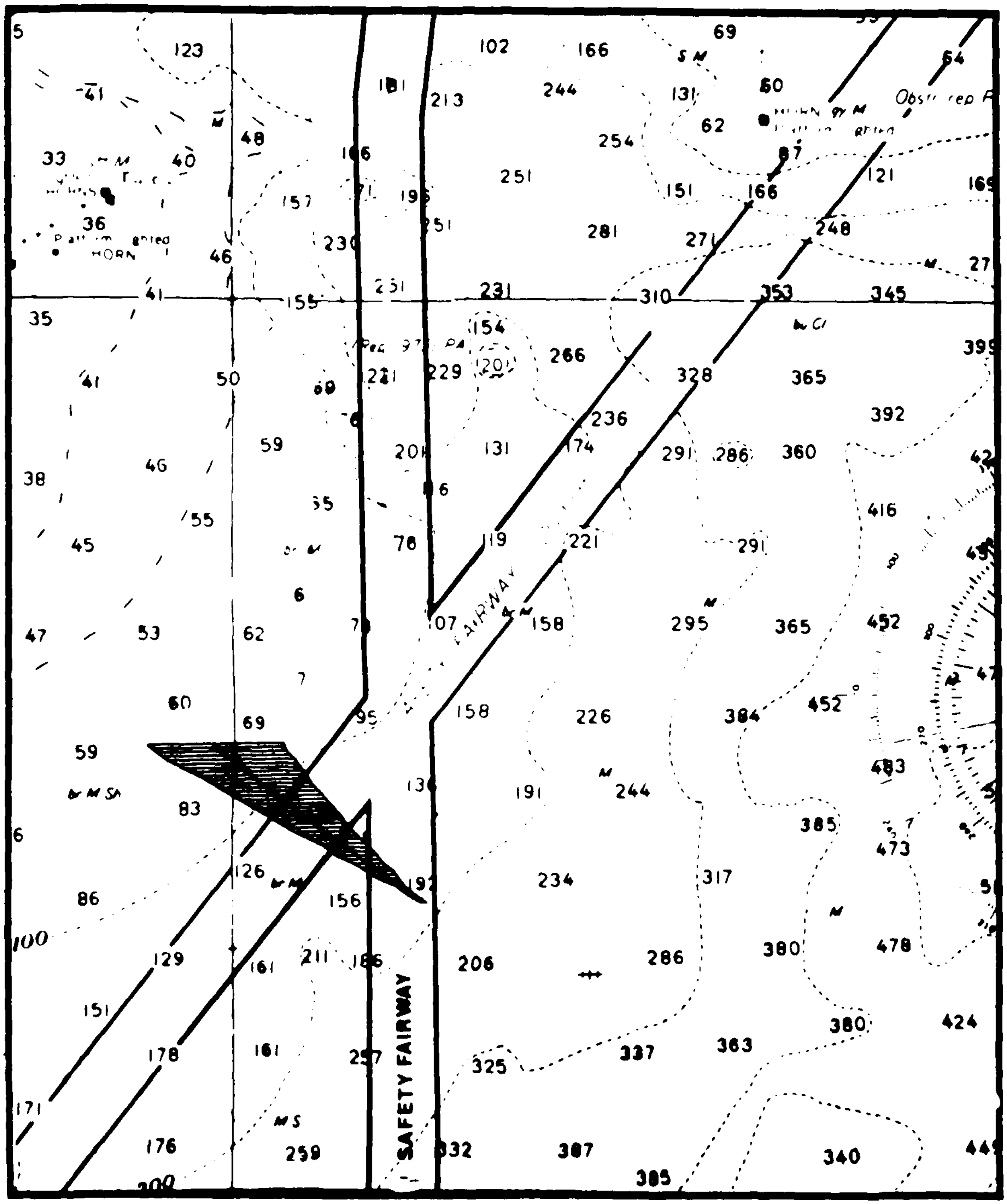


FIGURE B-40. TRADITIONAL ORGANIZATION – DEGRADED DEAD RECKONING APPROACH

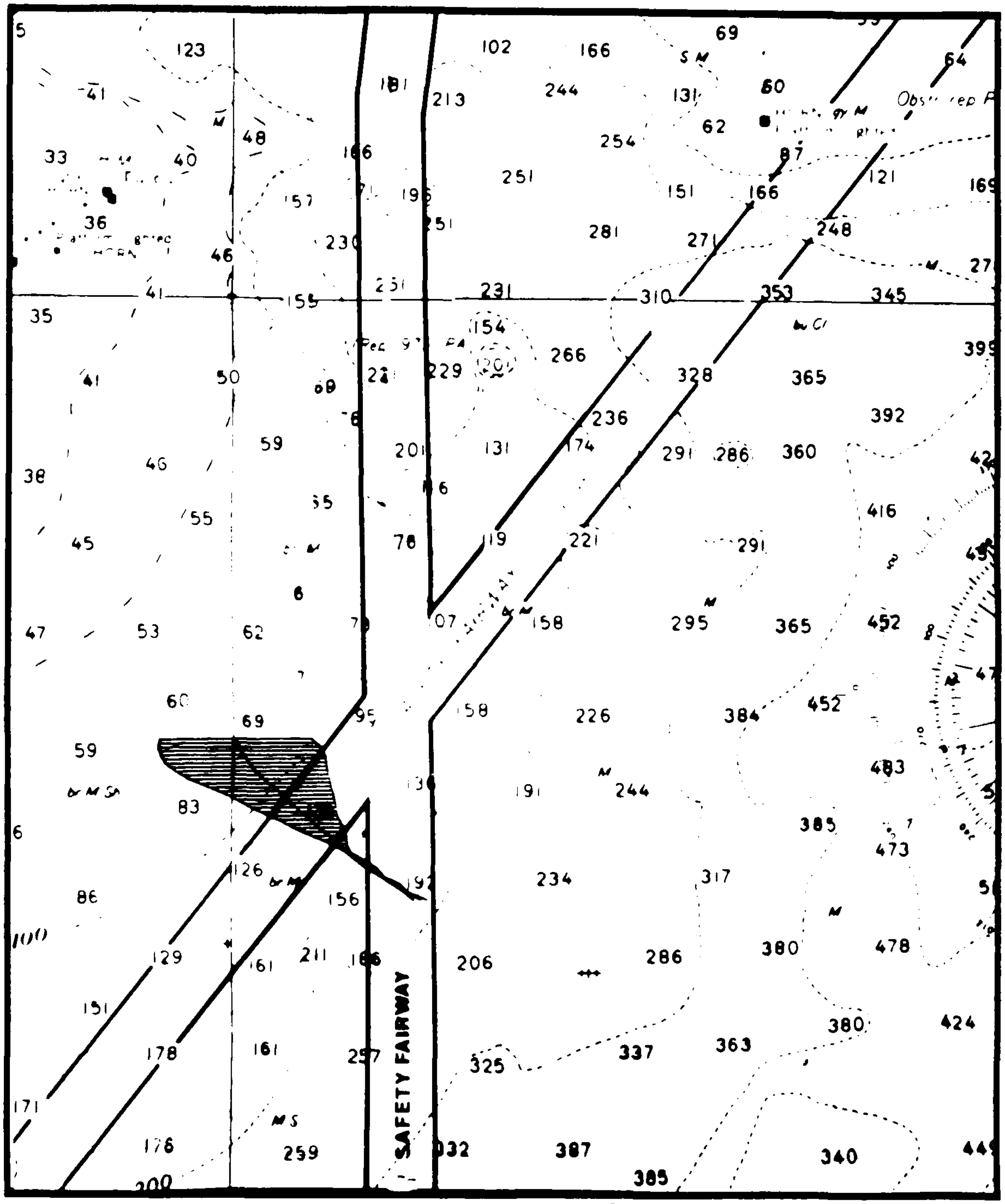


FIGURE B-41. TEAM ORGANIZATION – DEGRADED DEAD RECKONING APPROACH

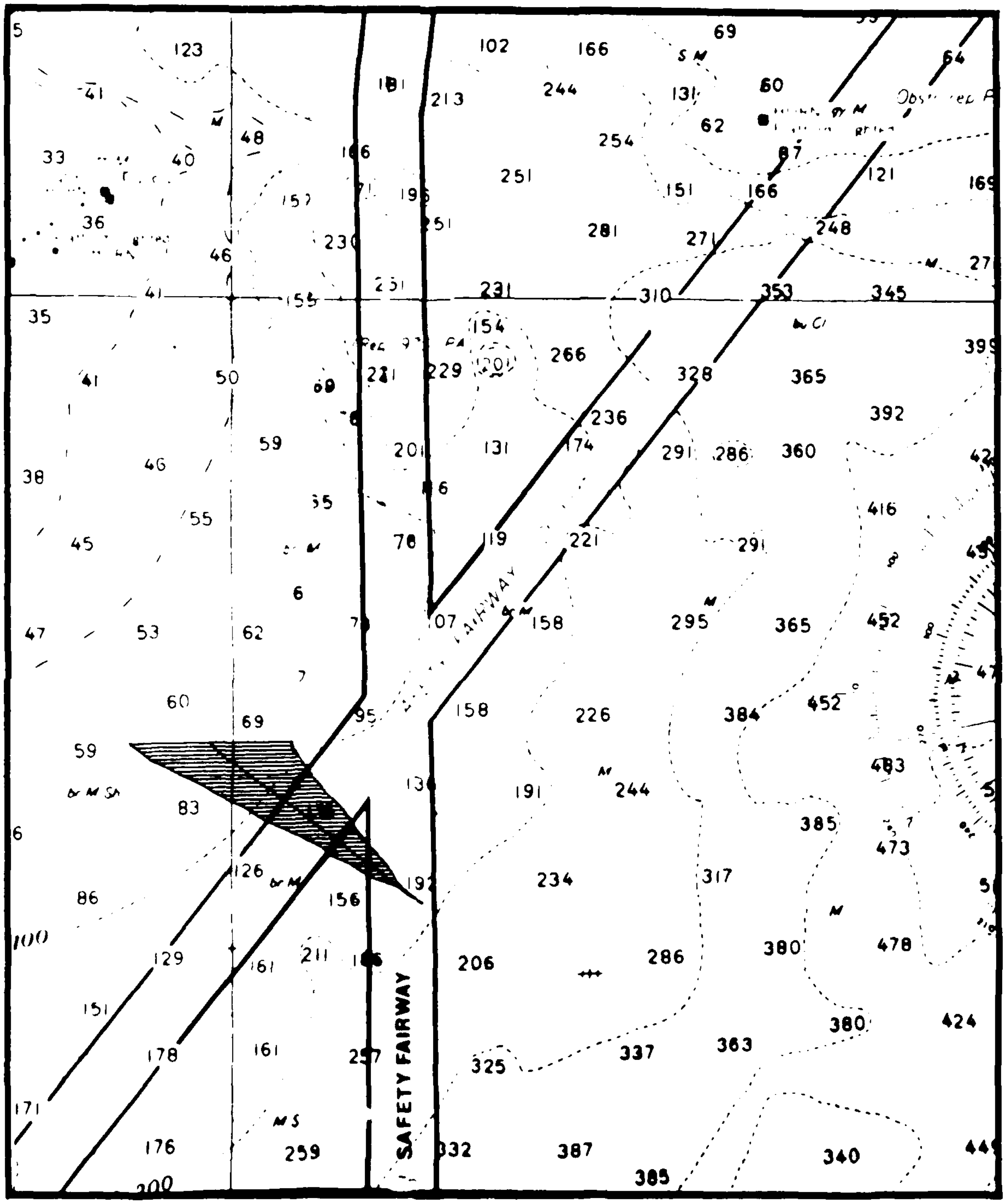


FIGURE B-42. RADAR, TRADITIONAL ORGANIZATION – DEGRADED DEAD RECKONING APPROACH

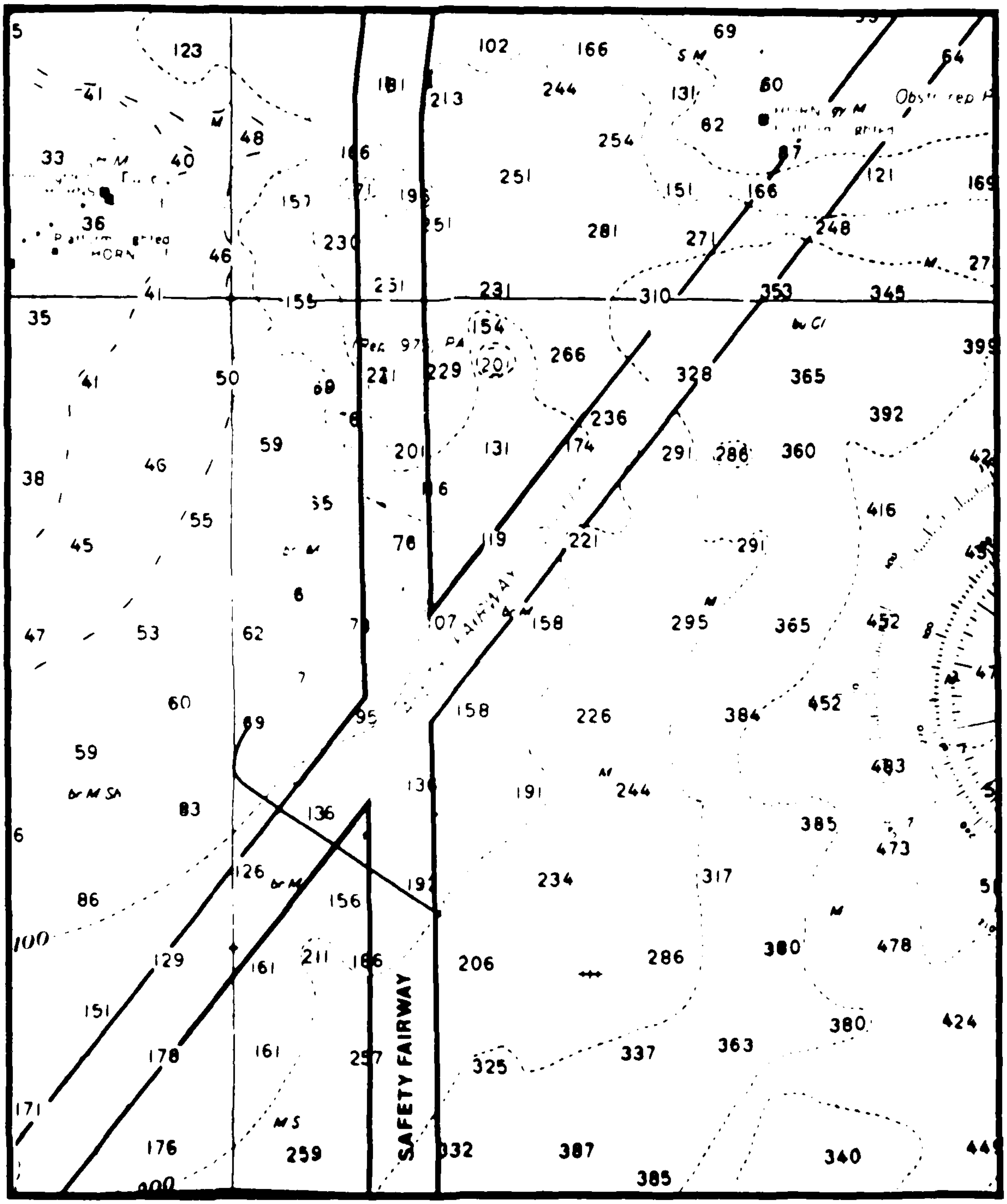


FIGURE B-43. RADAR, TEAM ORGANIZATION – DEGRADED DEAD RECKONING APPROACH

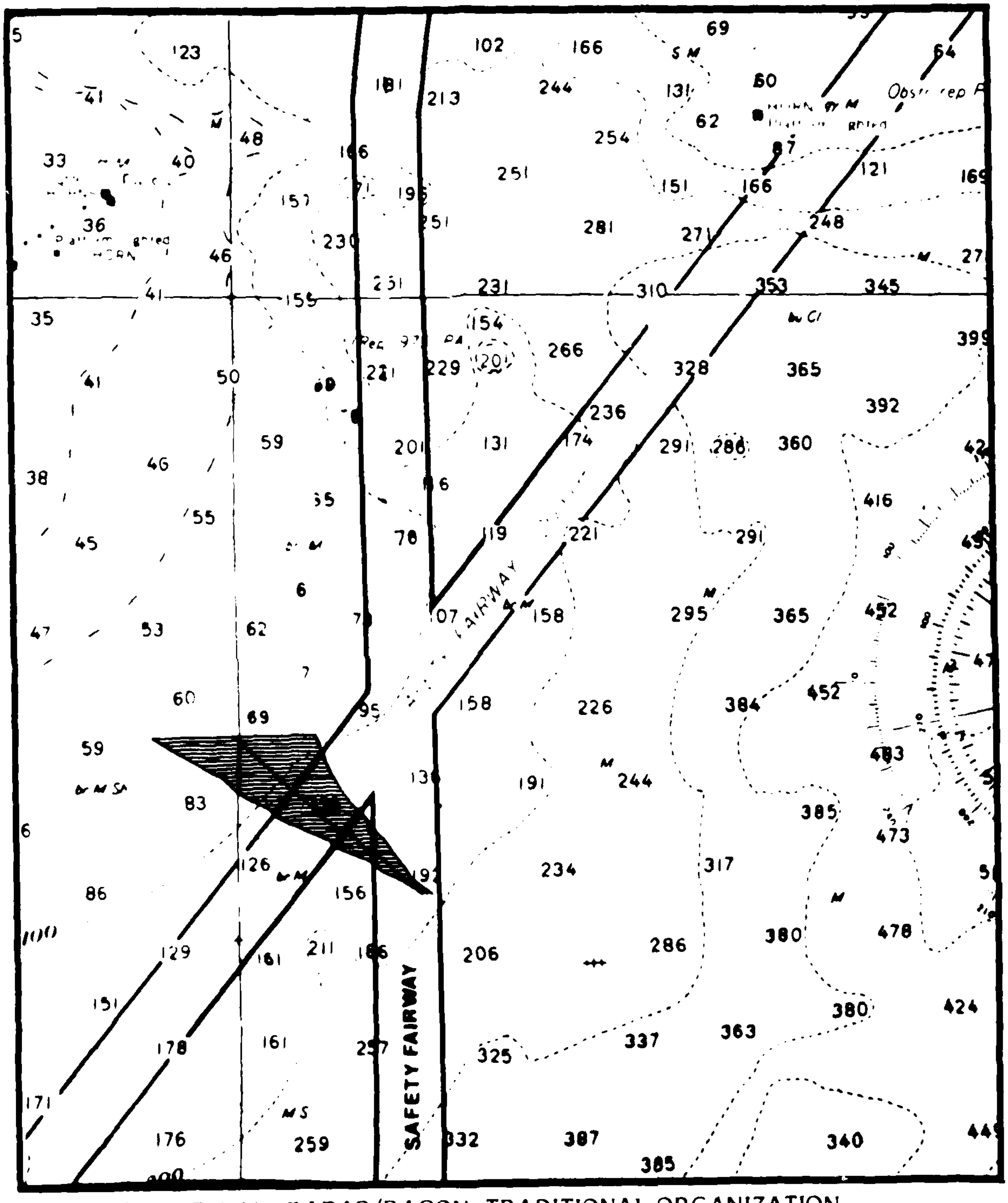


FIGURE B-44. RADAR/RACON, TRADITIONAL ORGANIZATION – DEGRADED DEAD RECKONING APPROACH

Appendix C

EXAMPLE OF QUESTIONNAIRES

PRERUN QUESTIONNAIRE

Briefly describe your plan for this run. (Include ETA, CPA to rigs, where will your begin to slow, etc.)

POSTRUN QUESTIONNAIRE

We are interested in your assessment of the run you have just completed. This questionnaire is designed as a self-evaluation of the transit.

1. How closely did you follow your initial strategy?

   ___ a. no change from initial strategy
   ___ b. some change from initial strategy
   ___ c. significant change from initial strategy
   ___ d. completely different strategy

2. Why did you select this track?

3. If your strategy changed, briefly explain why.

4. Did you meet your estimated time of arrival to any way points?

   ___ a. yes
   ___ b. no
   If no, why?

5. Did you initiate course changes?

   ___ a. too soon
   ___ b. too late
   ___ c. at an appropriate time

6. Did you maintain consistent speed throughout the run?

   ___ a. yes
   ___ b. no
   If no, why?

7. How did the ship traffic affect your strategy?

   ___ a. waited until the ship passed
   ___ b. ship did not affect strategy
   ___ c. other (explain)

8. Did you maintain sufficient distance from traffic and fixed objects?

   ___ a. too close
   ___ b. within enough distance
   ___ c. other (explain)

9. Did you ever have doubt as to your location? Check the appropriate box.

___ a. I was lost much of the time
___ b. I had doubt at one point of the run
___ c. I knew where I was through out the run

10. Was the pilotage conducted safely according to your own criteria?

___ a. Yes
___ b. No (explain)

11. What one feature of the display was most helpful during this run?

12. If you repeat this run, what one thing would you do differently?

13. Additional comments/observations

TO BE PROVIDED AND ANSWERED AFTER DISORIENTATION RUN

1. When did you first doubt the dead reckoning track?

2. Why did you question ownship's location?

3. Did you resolve the problem as efficiently as you could have with the available information?

4. What did you do when you realized ownship was no along the dead reckoning track?

POSTSIMULATION QUESTIONNAIRE

Part A: Enhancements

Answer the following questions by choosing:

a. Radar without racons
b. Radar with racons
c. ARPA
d. ARPA with navigation option

1. Rank the enhancements by putting the letter of the navigational tool in the appropriate spot.

_______ : _______ : _______ : _______
1 2 3 4

Most effective navigational tool — Least effective navigational tool

2. What were your criteria for choosing 1?

3. What were your criteria for choosing 4?

4. Would you use ARPA in the real world?

___ a. Definitely use ARPA
___ b. Probably use ARPA
___ c. May or may not use ARPA
___ d. Not likely to use ARPA
___ e. Definitely would not use ARPA

5. How much more helpful was the navigation option with ARPA?

___ a. Added a lot of relevant information
___ b. Added some relevant information
___ c. Added information not necessary
___ d. Do not want added information

6. When compared to radar alone, did the additional racons add:

___ a. Much significant information
___ b. Significant information
___ c. Little significant information
___ d. No significant information

7. Were the scope representations sufficiently realistic?

___ a. Yes
___ b. No (explain)

Part B: Scenarios

Answer the following questions by choosing:

a. Inside north/south fairway scenario
b. Outside north/south fairway scenario
c. Fairway approach scenario

8. Which scenario was easiest? _________ What made it easy?

9. Which scenario was most difficult? ___________ What made it difficult?

10. Would you have conducted all the transits under similar conditions on an actual ship?

___ a. Yes
___ b. No (explain)

11. Did the lack of visibility affect your transits?

___ a. Yes
___ b. No (explain

Part C: Ownship

12. Have you previously handled a similar ship at sea?

___ a. Yes
___ b. No

13. Was the ship maneuvering response realistic for its size, type, and loading condition?

___ a. Yes
___ b. No
If not, how would you have expected it to differ?

Part D: Navigation Conditions

14. Were the charts provided adequate?

___ a. Yes
___ b. No (explain)

15. Was the navigation information provided during the scenarios adequate?

___ a. Yes
___ b. No (explain)

16. What aids would you change keeping in mind the various operating conditions you might meet in this area?

17. What changes would you make in the configuration of the channel, anchorage or platform areas?

Part E: General Simulation

18. Was the bridge equipment adequate?

___ a. Yes
___ b. No

19. Did it function properly and was its arrangement characteristic of a "typical" merchant ship bridge?

___ a. Yes
___ b. No (explain)

20. Have you ever been a subject on a simulator before?

___ a. Yes
___ b. No

21. Did the simulation feel natural to you on the first transit?

___ a. Yes
___ b. No (how long did it take to become familiar with it?)

22. After two or three runs, did you recognize any elements of the situations?

___ a. Yes
___ b. No (explain)

23. Were you able to adapt to the simulator so that your responses were the same as they would be at sea?

___ a. Yes
___ b. No (explain)

24. Additional comments:

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